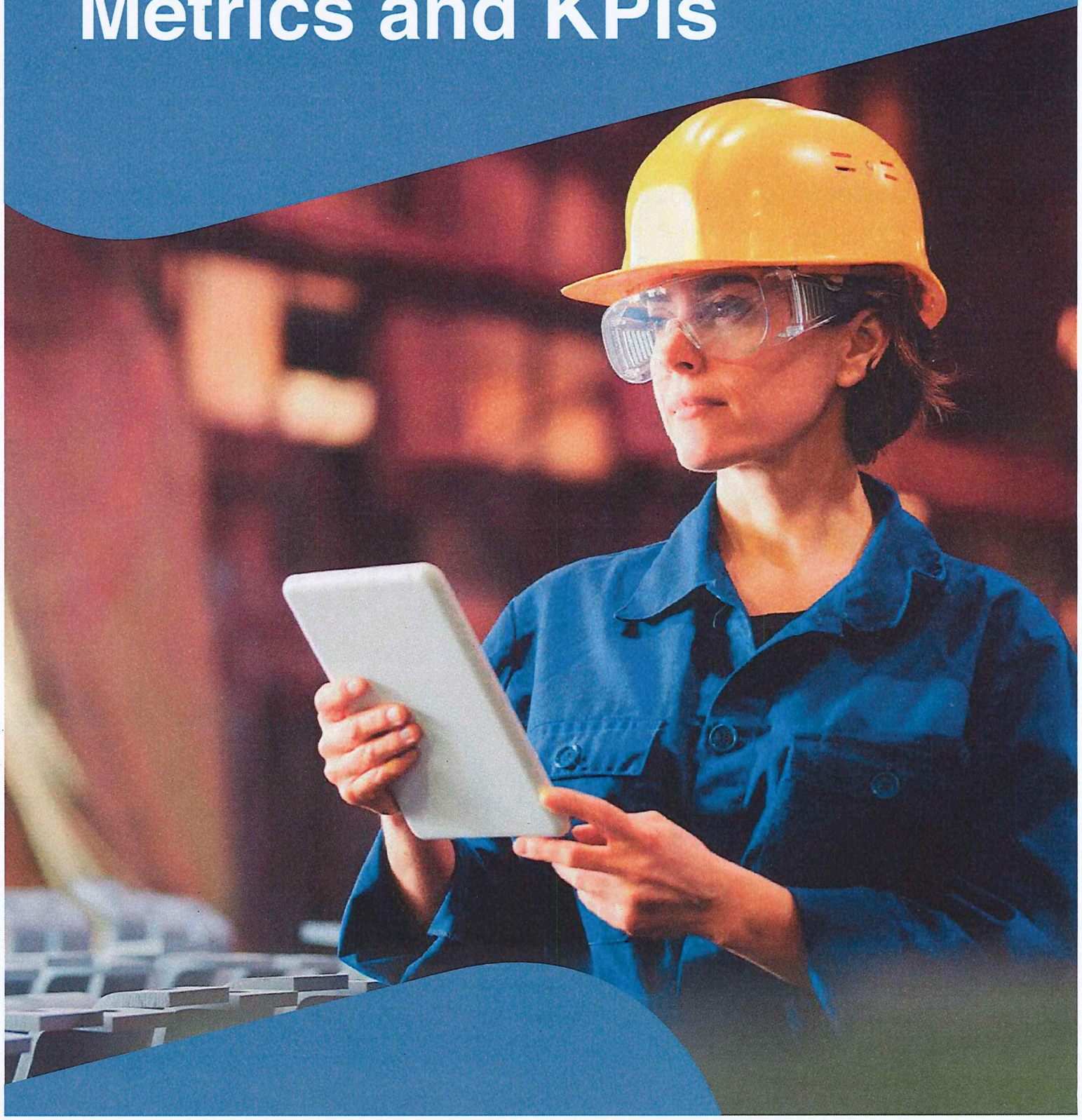
UpKeep

The Ultimate Guide to Maintenance Metrics and KPIs



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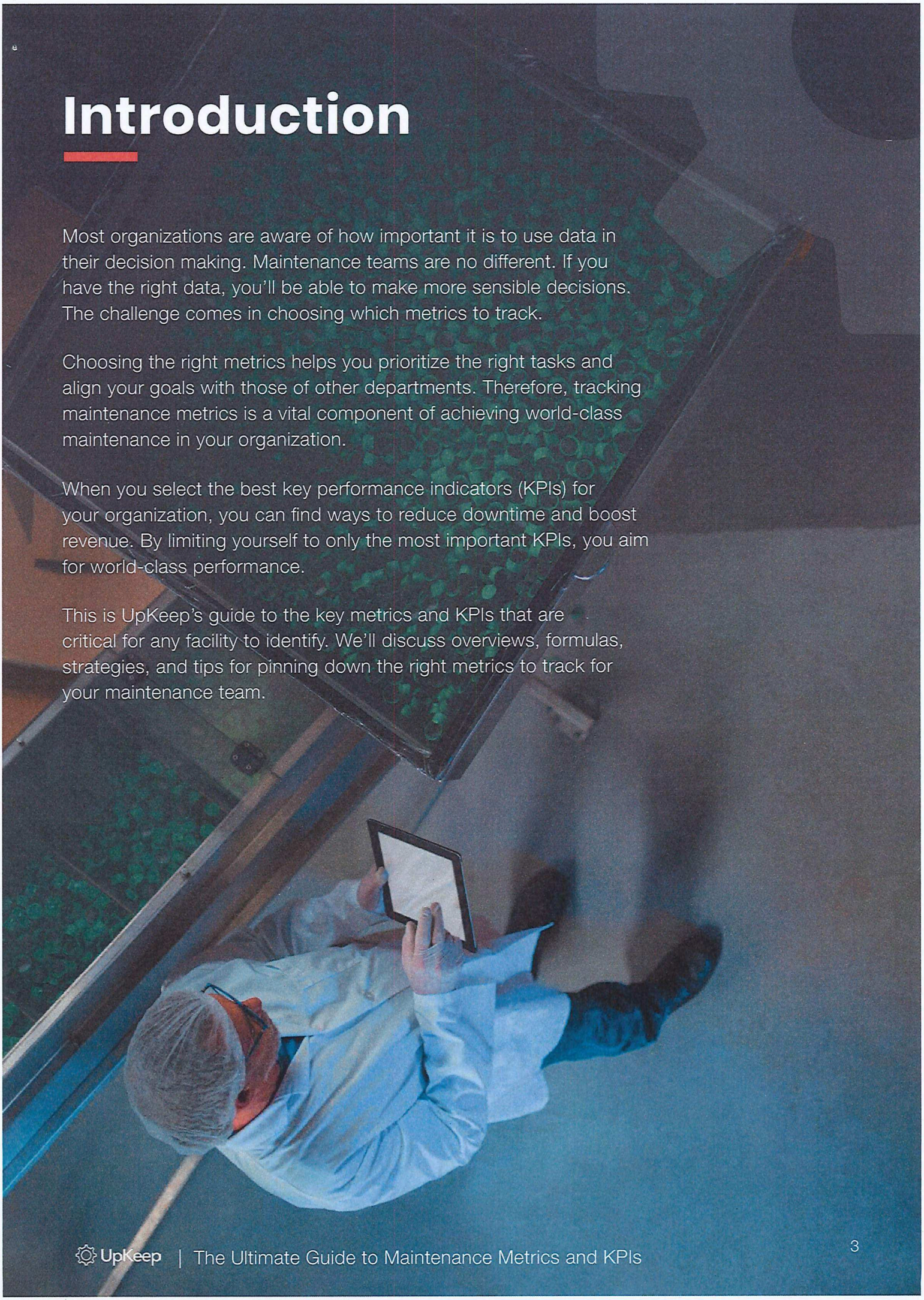
Introduction

Most organizations are aware of how important it is to use data in their decision making. Maintenance teams are no different. If you have the right data, you'll be able to make more sensible decisions. The challenge comes in choosing which metrics to track.

Choosing the right metrics helps you prioritize the right tasks and align your goals with those of other departments. Therefore, tracking maintenance metrics is a vital component of achieving world-class maintenance in your organization.

When you select the best key performance indicators (KPIs) for your organization, you can find ways to reduce downtime and boost revenue. By limiting yourself to only the most important KPIs, you aim for world-class performance.

This is UpKeep's guide to the key metrics and KPIs that are critical for any facility to identify. We'll discuss overviews, formulas, strategies, and tips for pinning down the right metrics to track for your maintenance team.



Terminology

What Is a Metric?

A metric is any number your organization might track. Each metric has its uses, and some may be more useful for marking progress than others, but all of them should give you some insight into what goes on in your processes.

For example, preventive maintenance schedule compliance may not tell you much about the company's profitability as a whole, but it does provide insight into how your maintenance processes are going.

What Is a KPI?

A key performance indicator (KPI), on the other hand, is a metric that provides insight into your organization's performance as a whole. Ideally, they're linked with business goals.

For instance, a manufacturer striving for top customer satisfaction will likely use customer rejects and satisfaction as key performance indicators. However, planned maintenance percentage and other maintenance metrics will likely be less useful here.

What Is the Difference Between Metrics and KPIs?

Metrics and KPIs are similar, as they both measure your company's performance against particular goals. Both look at current performance or measures, establish ideal levels for the future, and work toward those goals. The major difference is that metrics are a measurement of progress toward a goal; KPIs are target numbers to hit.

What Are Leading and Lagging Indicators?

Metrics and KPIs are generally classified according to whether they predict future performance or describe past performance. These are referred to as leading or lagging indicators, respectively.

Leading Indicators

Leading indicators are measurements that predict the outcome of a process or an event. These indicators are measured and are considered to be precursors of events or situations.

An example of a leading indicator is schedule compliance, when regarded as an indicator of the likelihood that an asset will experience unplanned failures and downtime. Because schedule compliance describes the amount of planned maintenance activities done on time, it can be correlated with how effectively maintenance activities are carried out, and therefore relate to increasing reliability.

> Leading KPIs lead to results; lagging KPIs are the results. If you are managing maintenance without accurate leading and lagging KPIs, then you are lost."
>
> -**Ricky Smith**, Vice President, World Class Maintenance

Similarly, the metric planned maintenance percentage can be considered a leading indicator as it affects the amount of unplanned downtime by aiming to keep assets running at optimal health. It also affects the required manpower as planned maintenance activities can be more efficiently scheduled.

Lagging Indicators

Lagging indicators measure the performance of the plant by looking at the outcomes and results of processes and operations. By analyzing the historical trend of the performance of the plant and its parts, reactive strategies can be applied to address underlying issues.

Examples of lagging indicators include mean time to repair (MTTR), mean time between failure (MTBF), and overall equipment effectiveness (OEE). Notice how these metrics are measured to confirm trends that have developed over time. Because these metrics are basically a historical record of performance, they can provide insights on which events in the past might have caused fluctuations to the plant's performance.

5 Considerations for Choosing Metrics to Track

When it comes to maintenance planning, you will likely focus on both lagging and leading indicators—the former to show your progress, and the latter to manage root causes. But as explained, choosing the right ones to track can be a challenge. How do you know what's worth tracking? These considerations may help in the decision-making process.

1 What Are Your Organization's Goals?

For starters, consider your goals. These can be any goals from your organization. For example, if your goal is to increase production, you'll need some metrics around maintenance to ensure that you're hitting your availability targets.

Of course, at lower levels, your goals would get more specific. In a manufacturing plant, for instance, you might have a goal to increase your conveyor system's uptime by a certain percentage. With that goal in mind, you'll be able to start looking at which leading indicators would support that. Make a list of possibilities to get started. Your list might include your preventive maintenance (as a percentage of total maintenance), your schedule compliance for the preventive maintenance, and your maintenance backlog.

2 What Are You Already Tracking?

When you have an idea of which indicators might help you meet your overall goals, determine what you're already tracking and start there. For some metrics, you'll need some time to get enough data to make it truly meaningful. As such, using those wouldn't be as economical as pulling from existing data.

In our conveyor system example, if you're already tracking preventive maintenance but not other metrics, start with that one. If you're not tracking schedule compliance or work order backlogs, you can't use those until you do, and getting that data together would take extra time.

At the end of the day, it's a return on investment calculation. What's the benefit and cost of tracking the metric? If that ratio is large enough (or at a minimum, the benefit outweighs the cost), then you should consider tracking it. But be careful with over-tracking metrics. Many companies track metrics but never use them for anything. Ask yourself these questions:

- What are you planning to use this for?
- What actions are you going to drive?
- What does this help you understand about your business?

3 What Type of Assets Are You Tracking?

The matter of which type of assets you're tracking is another important consideration. Different assets have different needs and purposes, and what would make sense for one might not be right for another.

For example, if you're tracking a mission-critical mixer, you'll likely want to focus on preventive maintenance, mean time to repair, and other such metrics. For something less important like lightbulbs in the men's bathroom, you're probably not too interested in the time it takes to replace those. Instead, measurements such as stockouts or other inventory metrics would be more relevant.

4 How Critical Is the Asset?

Criticality, of course, should always enter into your decisions on what metrics to track. A non-critical piece of equipment wouldn't be as important to track as one that's core to your process.

If an asset is at high risk of failure, and if that failure would have a significant impact on your process, you'll want to track it more carefully by monitoring leading indicators. For an asset that's less likely to fail and that wouldn't cause a significant disruption if it went down, surface-level monitoring with lagging indicators might be more appropriate.

Risk is also important. If it's low-critical equipment, but it fails multiple times daily, the risk is very high. Small, chronic failures are a big issue in manufacturing.

5 Cause and Effect Relationships

The last consideration is a matter of cause and effect. When choosing leading indicators, you'll need to determine whether they truly have an impact on your desired results. After all, metrics are only of any value if they are predictive in nature.

Often, finding whether a given metric is truly predictive of future success is a matter of trial and error. You start tracking the data, and then see if lagging indicators correlate with it.

Existing studies can also help you pin down cause and effect relationships. Back to our conveyor system example, studies show that preventive maintenance provides 12% to 18% cost savings over reactive maintenance, meaning there's a good chance that tracking and improving preventive maintenance as a metric would help reduce unplanned downtime.

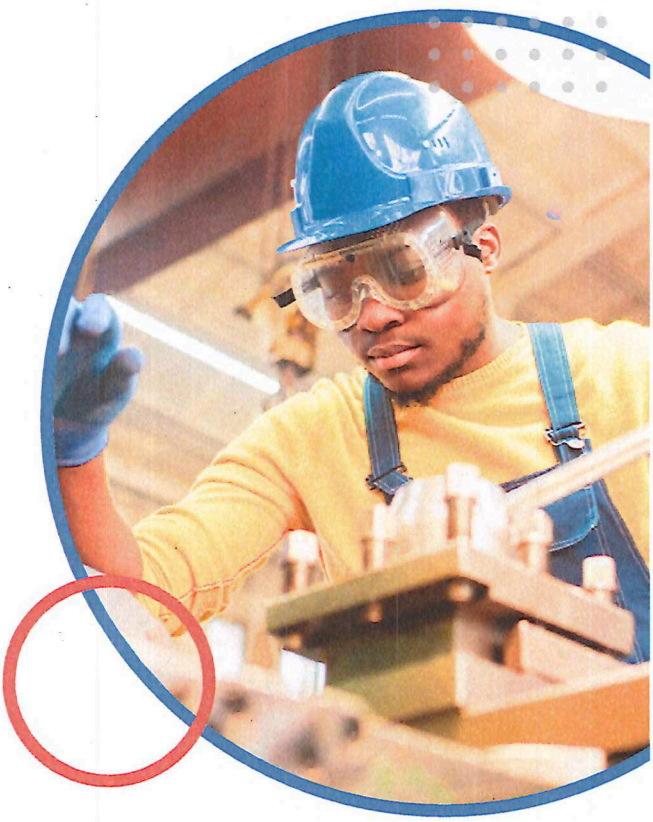
> "Maintenance metrics and KPIs to our organization aren't just a tool to evaluate our technician teams; they set the benchmark in which we build and modify processes, plan future decisions, and improve our operations upon. KPIs are a direct look into the important details and trends that are sometimes hidden by the day-to-day rhythm."
>
> -**Joe Faloon**, Vice President, Springfield Pepsi-Cola

Types of Maintenance Metrics

Not every maintenance metric is of equal importance to every company. Metrics that qualify as KPIs are dependent on your industry, your company's goals, and the types of assets you manage. When you select the best metrics and KPIs for your organization, you can find ways to reduce downtime and boost revenue.

Instead of placing equal importance on every metric you track, choose a few KPIs. You can also choose a few leading indicators that help you determine why KPIs are getting hit or being missed. For instance, if schedule compliance is a KPI, *percentage of work covered by a work order* may be a leading indicator.

Below, we explore different maintenance metrics that you can track as KPIs and leading indicators.



Equipment Downtime

Overview

Equipment downtime refers to the amount of time that equipment is not operating, whether that's a result of unplanned equipment failure (like a fault or broken part) or planned downtime (like necessary downtime for preventive maintenance). Typically, the term *equipment downtime* refers to unexpected downtime that accumulates any time the production process stops.

World-Class Standard

Aim for unscheduled downtime to be 10% or less, meaning that a facility's equipment should be running at 90% availability or greater.

Why It's Important

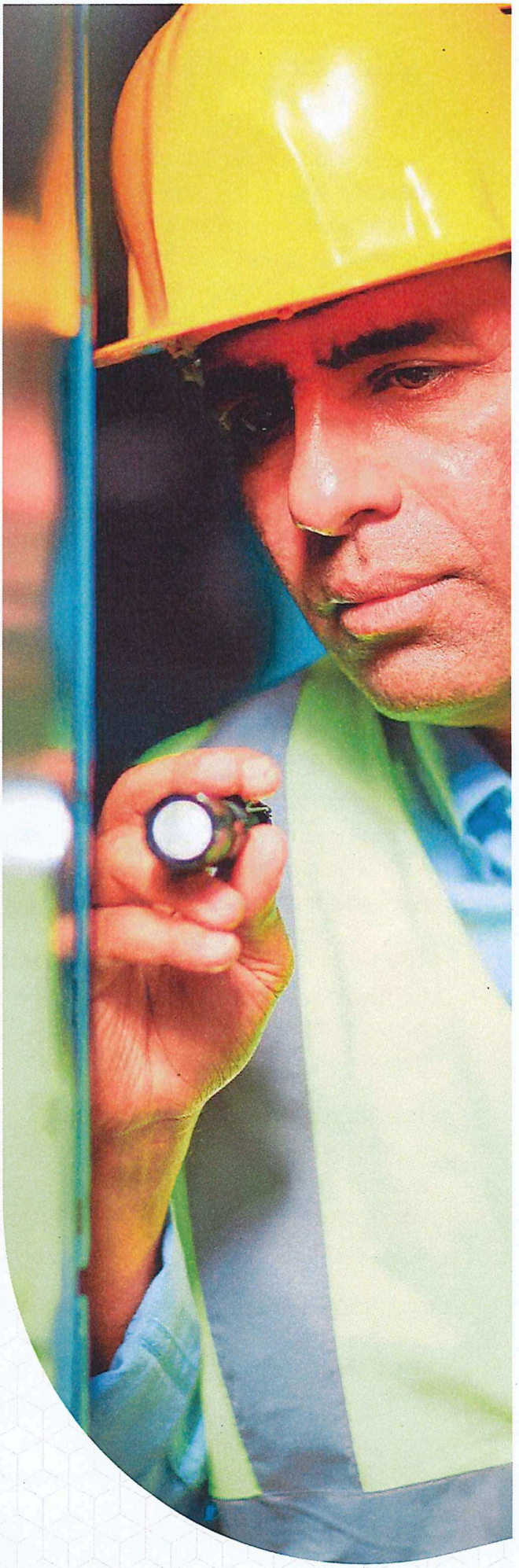
Tracking equipment downtime is particularly important for a few reasons. Having a good idea of a facility's typical uptime works as a diagnostic tool for the facility's maintenance and production efforts. For example, a high equipment downtime figure might mean that preventive maintenance isn't being performed properly, or that there are problems with how production is set up. On the other hand, a low maintenance downtime figure can indicate a generally healthy production environment.

This can be even more granular if equipment downtime is tracked on a per-area basis. If downtime is especially high in the final assembly portion of a production line, it's clear where improvements need to happen. In this way, tracking downtime becomes a method of mapping out the overall health of each individual part of an organization's production. While it can seem expensive to track downtime with a computerized maintenance management system (CMMS), there's a potentially far larger amount of money saved on knowing where issues lie and eliminating them.

How to Calculate

(Hrs of downtime / total period measured) * 100

Because the term *equipment downtime* can apply to any event that halts manufacturing, it's important for an organization to first figure out what kind of downtime they want to calculate.



MAINTENANCE BACKLOG

Overview

Usually measured in work days or weeks, the maintenance backlog as a metric quantifies the amount of time required for a defined number of workers to complete all pending maintenance tasks. Maintenance backlog is composed of activities related to preventive maintenance and any other outstanding maintenance such as required corrective maintenance.

It goes without saying that not all tasks in the backlog are equally urgent. Having some backlog is not necessarily a reason to panic—it can even be an indicator of optimized staffing. The dangers of maintenance backlog creep in when maintenance schedules are disrupted by emergency work and an inefficient prioritization model.

Neglected tasks in the maintenance backlog become deferred maintenance, inevitably causing more breakdowns and serious downtime. Breakdowns require immediate unplanned maintenance tasks that in turn disrupt scheduled activities. Disruptions to the schedule push more tasks into the backlog to continue the vicious cycle.

World-Class Standard

Aim to have a maintenance backlog of around six weeks worth of tasks per technician.

How Much Backlog Is Too Much?

Maintenance backlog provides a list of things to do over a certain period of time. Having some amount of backlog is generally acceptable. Having no backlog may be indicative of overstaffing. The idea is not to eliminate the backlog but to manage it.

The exact ideal amount of backlog may vary for each business, but the idea remains that some amount of pending work can be a useful metric when managed properly.

The important point in measuring maintenance backlog is defining how it's measured. Agree with the team and with your stakeholders on what constitutes the maintenance backlog.

How much of it is preventive maintenance, and how much of it is corrective maintenance? Differentiate between tasks and delegate maintenance work accordingly, so that the workforce is utilized more effectively towards managing the backlog.

MEAN TIME BETWEEN FAILURE (MTBF)

Overview

Mean time between failure (MTBF) as a maintenance metric indicates the duration that an equipment operates without disturbances. This intuitively relates to the availability of the equipment. Availability, also known as uptime, is one of the key indicators of overall equipment effectiveness and is always a focus area for improving productivity. An equipment's total uptime can be expressed in terms of the MTBF together with another metric, the MTTR (mean time to repair).

It is important to note that MTBF is applicable only to repairable items. Manufacturing processes can use it to plan for contingencies that require the repair of key equipment. Being aware of this data provides insights for making sound decisions for the plant. There's also mean time to failure, which is for non-repairable equipment.

World-Class Standard

Varies based on equipment type.

How to Calculate MTBF

The MTBF is calculated by taking the total time a piece of equipment is running (i.e. uptime) and dividing it by the number of breakdowns that occurred over the same period.

MTBF = total uptime / # of breakdowns

How to Improve MTBF

Increasing the MTBF increases the uptime of equipment. Keeping track of the MTBF for each piece of equipment, especially those that require continuous operation, allows the maintenance team to efficiently schedule maintenance activities.

The first step to improving MTBF is to make sure that the data being collected is accurate. Development of tools such as various maintenance software can ensure that data is being recorded correctly and accurately.

The next step to gathering data is using it to proactively perform preventive maintenance. Investing the time to perform maintenance checks and activities such as checking for proper lubrication, aligning calibration systems, and cleaning pays off by significantly reducing the number of major stoppages due to breakdowns.

> "A key and fundamental metric for my organization is corrective work generated from preventive. This is quantified by task fail work order generation and viewed as a percentage of overall work orders. This fundamental process keeps the technicians engaged in fail finding at the right time during schedule service."
>
> -**Bryan Bieschke**, Director, Maintenance & Reliability, T. Parker Host

MEAN TIME TO REPAIR (MTTR)

Overview

Mean time to repair (MTTR) is the average time it takes for equipment to be diagnosed, repaired, and recovered after experiencing a failure. It's a metric that is used to assess maintenance effectiveness.

One of the factors that contributes to a plant's overall equipment effectiveness is the availability of the equipment to perform its functions. When equipment experiences downtime, especially due to failures, its availability is negatively impacted and therefore reflects poorly on the overall productivity of the system.

By keeping a data-driven mindset and proactively improving the MTTR, the manufacturing processes can reduce availability losses due to repairs. The idea is to speed up the equipment's rate of recovery from failures and breakdowns. Minimizing the MTTR values of equipment is a step towards maximizing a plant's productivity.

World-Class Standard

Though diligence in noting reliability and availability data has improved over the years, the method of measuring metrics such as MTTR has no clear industry standard.

Keeping in mind potential inconsistencies in recording data, it's important to always define the methodology by which variables within the operations are measured. This provides a transparent guide for internal teams and external stakeholders alike.

How to Calculate MTTR

The MTTR is equal to the average duration of each stoppage due to failure. This is calculated by taking the total downtime that goes into the repair and recovery of equipment, divided by the number of times that the same equipment has stopped its operations.

MTTR can be written in the form of the formula:

MTTR = total downtime / # occurrences of stoppages

Note that the MTTR formula in itself is not dependent on the span of time in which the equipment operates (i.e. uptime). MTTR is only quantified by the average time each stoppage lasts, regardless of the period between the instances of downtime.

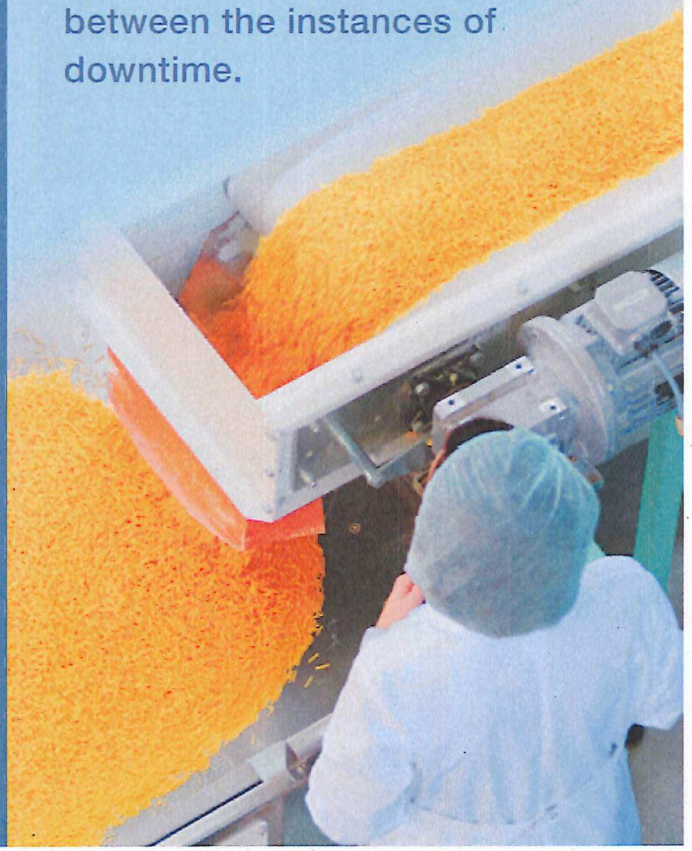
How to Improve MTTR

The most effective way to reduce MTTR is to get to the root cause of the failure before it even occurs. Closely monitoring operational data of each piece of equipment in the plant enables the early detection of possible causes of failure. In today's setting, these tasks can be completed more easily and accurately with tools such as CMMS software.

Performing preventive maintenance on equipment addresses most issues that eventually lead to major breakdowns. When equipment is routinely scheduled for inspection and maintenance work, points of failure are identified early, and the resulting MTTR is relatively short.

Another way to improve MTTR and increase availability is to map out and plan ahead for possible breakdown scenarios. Anticipation of possible breakdown causes can better equip the team with efficient solutions to quickly resolve issues.

The MTTR formula in itself is not dependent on the span of time in which the equipment operates (i.e. uptime). MTTR is only quantified by the average time each stoppage lasts, regardless of the period between the instances of downtime.



OVERALL EQUIPMENT EFFECTIVENESS (OEE)

Overview

Overall equipment effectiveness (OEE) is a standard used for measuring plant performance. Calculating a plant's OEE helps identify areas that are holding the plant back from performing at maximum capacity.

World-Class Standard

Three main factors drive a plant's performance: availability, performance efficiency, and rate of quality products. Seiichi Nakajima, who conceptualized and introduced OEE, provides ideal scores for each of these factors to achieve a world-class OEE rating:

- Availability > 90%
- Performance efficiency > 95%
- Rate of quality products > 99%

Aim to have an OEE of **77% or greater**.

How to Calculate OEE

To calculate OEE, three main factors need to be defined and quantified:

1. Availability

Availability quantifies the amount of time that equipment is able to perform its function. It's calculated as the ratio of the actual operation time to the available time per day, where the available time per day is equated to a full working shift.

Availability = (available time - planned downtime) / available time

2. Performance Efficiency

Performance efficiency quantifies how much longer it takes to complete a process compared to its ideal cycle time.

A simplified calculation is taken by multiplying the number of processed units by the ideal cycle time, then dividing the product by the actual operation time.

Performance efficiency = [(# processed units * ideal cycle time) / actual operation time]

3. Rate of Quality Products

Rate of quality products quantifies how much of the total produced units are within the acceptable standards of good quality.

For a batch of 440 units produced with only 435 units of acceptable quality, the rate of quality products is calculated to be 97.73%.

Rate of quality products = (# units of acceptable quality / # units produced)

4. Overall Equipment Effectiveness

The OEE is then calculated by taking the product of its three main factors.

OEE = availability * performance efficiency * rate of quality products

How to Improve OEE

Being aware of the factors contributing to the OEE allows for proper planning to proactively reduce process inefficiencies and losses. Clearly, improving one or all of the factors will in turn improve the OEE of the plant.

A good start to boost the plant's effectiveness is to **eliminate the "six big losses"** that every manufacturing unit should be aware of.

Each of these six points directly impact at least one of the factors that constitutes the overall effectiveness. Addressing these losses will inevitably lead to an improved OEE.

Avoid Equipment Failure

Refers to mechanical breakdowns of key equipment, or generally any unplanned downtime that can cause a significant decrease in availability

Expedite Setup and Adjustment

A period of reduced or stopped activity (usually planned) when equipment is being set up and adjusted (e.g. system preparations, warmup, maintenance)

Minimize Idling and Minor Stoppages

Minor interruptions in production that can cause unnecessary increases to the production time

Troubleshoot Reduced Speed

Occurs when equipment is running at increased cycle times that vary too much from ideal levels

Minimize Defects in Process

Any errors along the processing flow that add flaws to the finished product, and therefore a decrease in the number of quality products

Prevent Reduced Yield

Occurs when equipment is not working under the optimal conditions to produce products within the acceptable quality standards (e.g. units produced while the equipment has just started running or is being set up)

PLANNED MAINTENANCE PERCENTAGE (PMP)

Overview

Planned maintenance percentage (PMP) is a percentage that describes the amount of maintenance time used towards planned maintenance tasks, which is measured against the total amount of maintenance hours in a given time period (weeks, months, years).

The PMP metric exists because it's useful for organizations to track how their maintenance time is spent. While a planned maintenance percentage shows an organization how much time is spent performing planned maintenance, it also shows how much time is spent fixing reactive/corrective issues and unplanned downtime events.

Calculating a facility's PMP is a useful way of determining what issues need to be combated. For example, if the PMP is low (which means a small amount of maintenance hours is being spent on planned maintenance), there could be a problem with production equipment that's keeping it from functioning at an appropriate level. In this way, PMP is not only a measurement tool for planned maintenance efficiency but also a diagnostic tool.

World-Class Standard

Aim to have a planned maintenance percentage of >85%.

How to Calculate PMP

You can calculate PMP with the following equation:

(Planned maintenance hours / total maintenance hours) * 100

SCHEDULE COMPLIANCE

Overview

Organizations that are committed to measuring the effectiveness of their scheduled maintenance process use schedule compliance as a performance metric. Maintenance activities are typically scheduled over the course of one week, and schedule compliance is measured over the same period, although time periods may vary by organization. It's critical that managers create a formal process that promotes periodic review of results and open discussion for areas of improvement.

Manufacturing organizations benefit the most from tracking schedule compliance when properly implemented. By definition, the organization is required to proactively create a work schedule to adhere to. In manufacturing plants, scheduled maintenance typically means machine downtime which forces close communication and coordination between schedulers, operators, mechanics, and other plant personnel.

World-Class Standard

Aim to have 90%+ schedule compliance.

4 Tips for Implementing Schedule Compliance

A strategy on implementing schedule compliance properly could mean the difference between acceptance or backlash.

Here are some practical tips:

Define the Purpose

We have established what schedule compliance is and how it's a critical metric used to improve reliability and productivity. When you present this metric, get specific on what reliability and productivity mean and how all personnel benefit from improving them.

Gain Alignment

Get buy-in from leadership at all levels. Educate and empower supervisors and managers on how to respond to any concerns or objections from employees. A common concern can be the time frame involved in calculating compliance. Maintenance teams that have too many "emergencies" will not agree to shorter time frames as they are less likely to be able to comply with scheduled work. It will be up to management to decide how to properly implement schedule compliance in a way that does not de-motivate personnel.

Encourage Transparency

The true test to your culture will come once you have data to analyze and start asking the "why" questions. Condition your teams to have uncomfortable conversations. If transparency is new to your organization, consider recognizing or rewarding behaviors that support your new need for candor. A technician that does not finish a task on time may one day admit he has not fully understood how to calibrate the new piece of equipment. How his supervisor responds to this will either encourage or discourage more of the same honest behavior.

Get Feedback Along the Way

Your formal plan for measuring schedule compliance must include a way of collecting input from all employees. Having a mechanism that allows personnel to proactively give input or ideas enables management to evaluate and make adjustments. It also tells employees that the organization is listening to them.

OTHER IMPORTANT MAINTENANCE METRICS

Maintenance cost as a percentage of RAV is a metric that shows how cost-effective your maintenance efforts are, where RAV stands for replacement asset value. One percent is considered world-class.

Average days to complete work orders may be used to determine whether a maintenance team is becoming more productive. However, this should be measured alongside failure-related metrics to ensure that faster maintenance doesn't result in more failures.

Percentage of work covered by a work order shows how much maintenance activity you're logging in your maintenance software. In addition to helping measure data acquisition efforts, this metric also measures a maintenance team's degree of organization. The goal is to reach 100%.

Maintenance overtime helps you understand whether you need more people on your maintenance team. Having a little overtime is good, but having too much can lead to employee burnout and excessive labor costs. The goal is to achieve around 5%.

FORMULA GUIDE

Equipment Downtime

[(Hours of downtime / total period measured) * 100]

Mean Time Between Failure

MTBF = total uptime / # of breakdowns

Mean Time to Repair

MTTR = total downtime / # occurrences of stoppages

Overall Equipment Effectiveness

OEE = availability * performance efficiency * rate of quality products

Availability = (available time - planned downtime) / available time

Performance efficiency = [(# processed units * ideal cycle time) / actual operation time]

Rate of quality products = (# units of acceptable quality / # units produced)

Planned Maintenance Percentage

(Planned maintenance hours / total maintenance hours) * 100

> "There was a lack of discipline around metrics. We had a very good standard, but not a lot of people knew about it or took the time to learn the contents, which resulted in a misunderstanding of metric definitions, calculations, and how they should be used. It also seemed like metrics drove reactive behaviors and siloed competition where different areas of the business would do what was necessary to make their metrics look good, but at the detriment of another area's metrics."
>
> -**Tim Rice**, Principal Consultant, The Defect Elimination Project

Conclusion

Metrics and KPIs are the critical measuring sticks to help keep your facility up and running and operating efficiently. By selecting a handful of metrics and KPIs, your management team can make changes and measure their effectiveness.

Choosing the right metrics is a process that depends on the asset, its criticality, and your business objectives. Sometimes you have strong research to support choosing particular metrics. In other instances, you might need to do some trial and error to find out what's really worth measuring. In either case, as you choose the right metrics to track, you'll improve your maintenance planning and help your maintenance team become more efficient.

Learn More

The right CMMS can track many different metrics, KPIs, and objectives. Try out UpKeep today to revolutionize your maintenance team and achieve KPIs for your business.

Free Product Tour

Check out www.onupkeep.com for more educational content on metrics, KPIs, and other important maintenance topics.

About UpKeep

UpKeep was founded in 2015 by our CEO, Ryan Chan. The CMMS he used while working as a process development engineer in a manufacturing plant was too complicated, so he learned how to code and created the first version of UpKeep.

Today, UpKeep is a team of 100+ people from around the world who are dedicated to making maintenance software easier to use and adopt.

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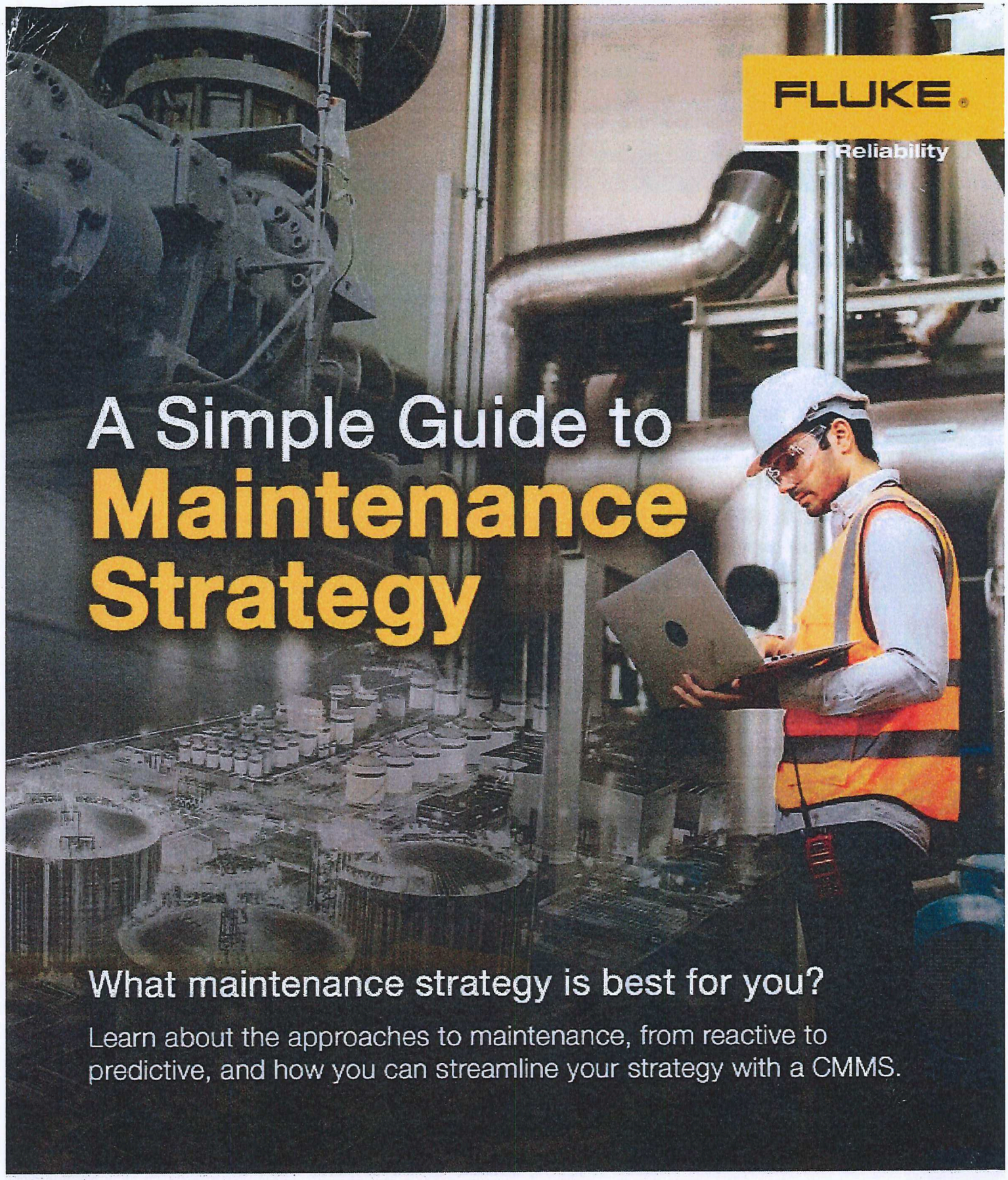
FLUKE
Reliability
A Simple Guide to
Maintenance
Strategy
What maintenance strategy is best for you?
Learn about the approaches to maintenance, from reactive to predictive, and how you can streamline your strategy with a CMMS.

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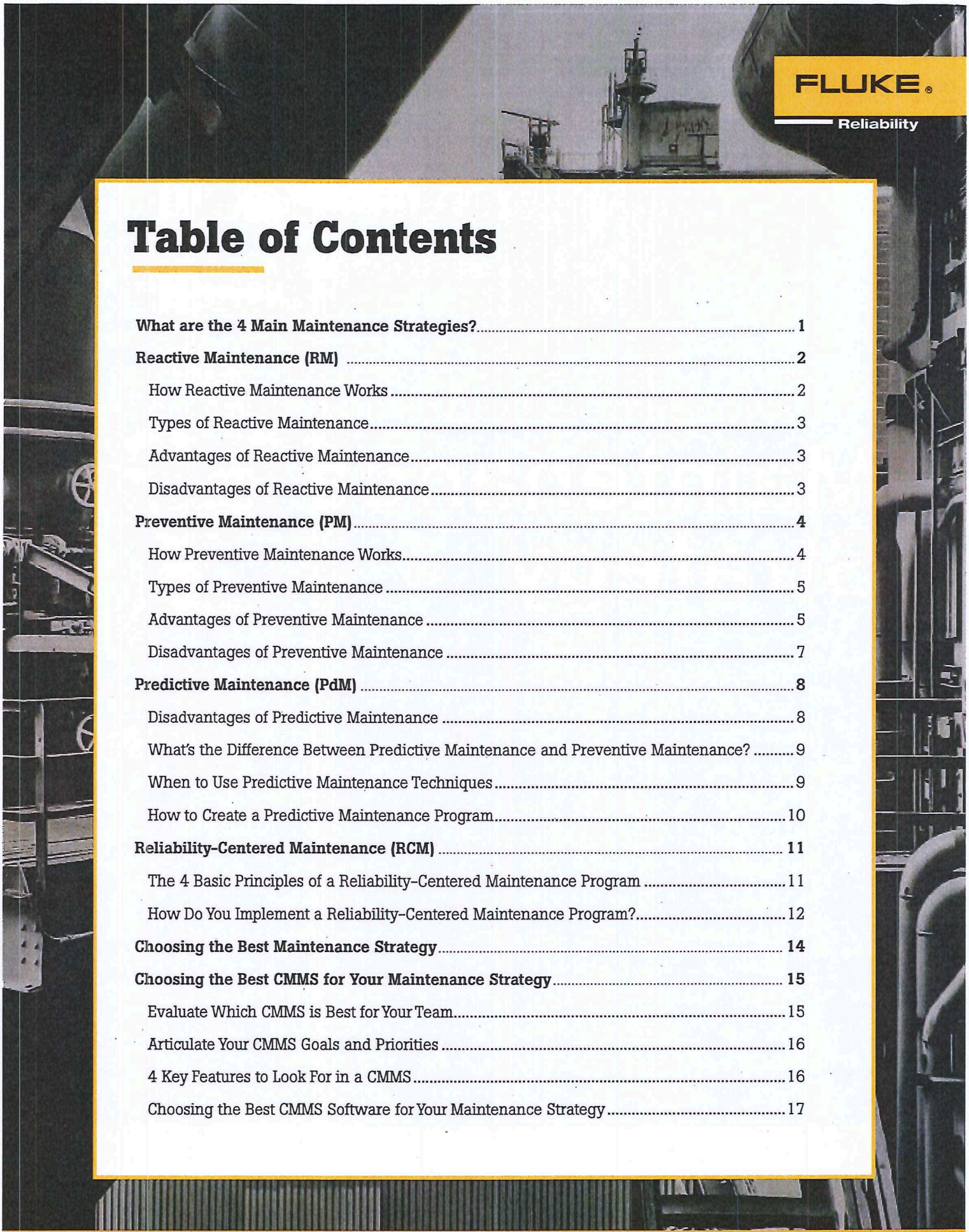

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What are the 4 Main Maintenance Strategies?

A comprehensive maintenance strategy is a decision-making framework for managing and optimizing asset health and performance.

Over the past decade, Industrial Internet of Things (IIoT) technology has transformed maintenance principles, enabling organizations to install smart devices that monitor the manufacturing floor and evolve their strategies.

This guide shares the four primary maintenance strategies in use today, along with their advantages and disadvantages:

1 Reactive Maintenance (RM)

Reactive maintenance is the strategy of performing maintenance on assets only after they fail.

2 Preventive Maintenance (PM)

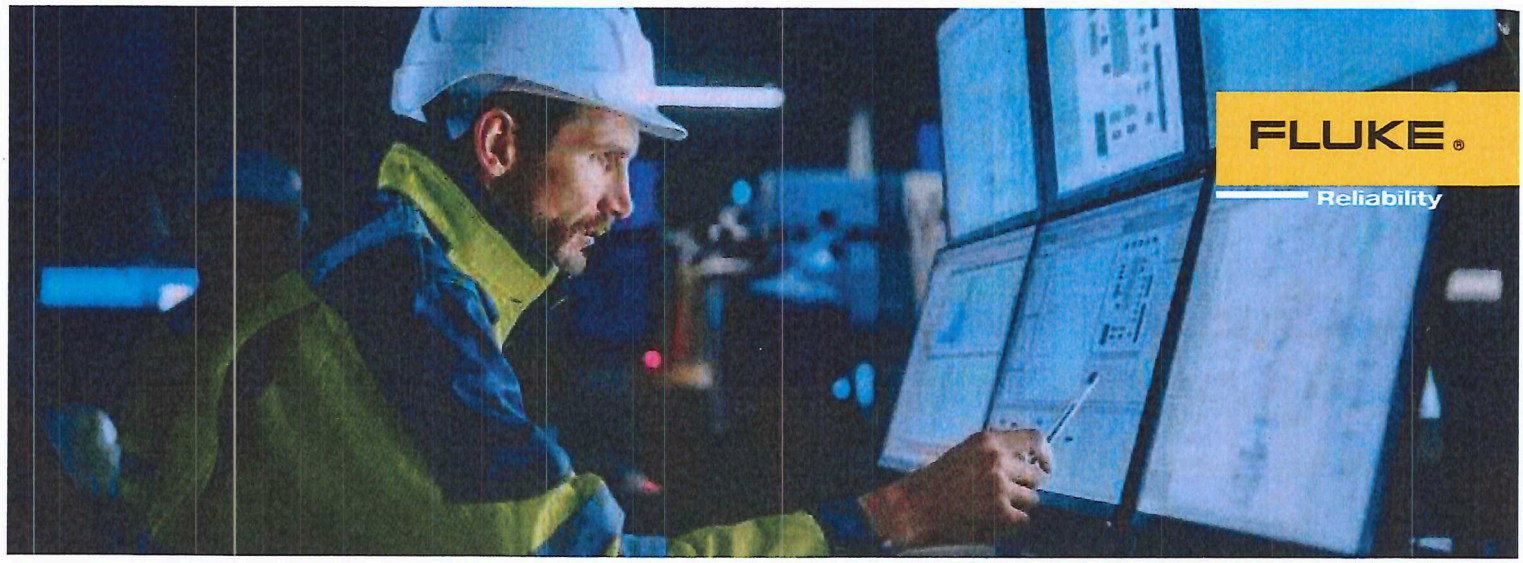
Preventive maintenance is scheduled to perform before failures occur, often on a time-based or usage-based cadence.

3 Predictive Maintenance (PdM)

Predictive maintenance is a strategy that harnesses the power of data, especially condition monitoring, to see failures coming so you can perform maintenance on the right asset at the right time.

4 Reliability-Centered Maintenance (RCM)

Reliability-centered maintenance is a strategy which involves building a plan to achieve optimal uptime for each part, component, and/or asset based on data trending and analysis with the goal of maximizing the reliability of an entire network of assets in the long term.



Reactive Maintenance (RM)

Reactive maintenance, sometimes discussed as breakdown or run-to-failure (RTF) maintenance, involves sending a team to repair assets only after they fail. When production halts, the plant supervisor will utilize available resources to coordinate a work order. A reactive maintenance strategy may be used as a cost-cutting approach, as other methods of maintenance may seem expensive or out-of-reach for cash-strapped operations.

However, reactive maintenance is not a practical solution in the long term for repairable assets. If a critical failure occurs, it can cause unnecessary delays in production that can cost more in lost production time than it would have cost to implement a more proactive maintenance strategy in the first place.

Despite its shortcomings, reactive maintenance is justified for replacing unrepairable items which should be employed on non-essential or low-cost equipment.

How Reactive Maintenance Works

Reactive maintenance can be either planned or unplanned. For example, some level of reactive maintenance is inevitable. Machines will sometimes fail when you don't expect it. This type of reactive maintenance is unplanned. And obviously, it's key to get these assets back up and running as quickly as possible. This is also known as breakdown maintenance.

However, other types of reactive maintenance are planned, as in the case of a run-to-failure maintenance strategy. Run-to-failure refers to a maintenance approach that waits until equipment fails before maintenance is completed. The goal of run-to-failure programs is often to save costs and reduce disruptions, although this approach can backfire and lead to greater losses due to unplanned downtime.

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Types of Reactive Maintenance

1 **Run-To-Failure Maintenance**
A planned breakdown maintenance strategy in maintenance. Assets are intentionally run until they break down, and only then are they repaired or replaced. Planned.

2 **Corrective Maintenance**
Any maintenance that restores or repairs a problem with an asset, returning it to normal working condition. Planned or unplanned.

3 **Breakdown Maintenance**
Maintenance performed on assets after they have failed. Unplanned.

Advantages of Reactive Maintenance

Reactive maintenance is not the ideal strategy for all of your maintenance operations; however, it does have its place and some advantages when used strategically. For example, it is important to have processes and a strategy in place in the event that assets fail, but it shouldn't be your default approach.

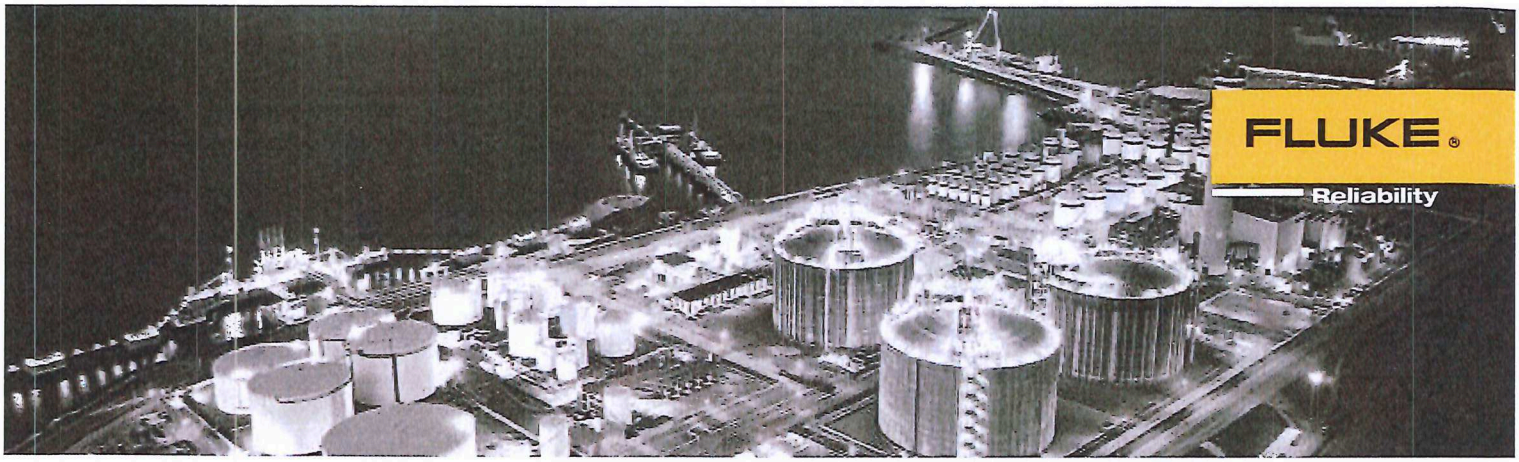
Reactive maintenance can save time and initial costs because there is very little planning required and no upfront investment. In addition, reactive maintenance can be used strategically in the short term for less critical assets, allowing maintenance teams to focus their preventative and predictive maintenance efforts on the highest impact assets first.

However, any type of reactive maintenance should be no more than a short-term or backup strategy; otherwise, the risks and potential costs will significantly outweigh any short-term benefits.

Disadvantages of Reactive Maintenance

While the initial cost and time savings of reactive maintenance can be enticing, it is important to understand the disadvantages of relying too heavily on a reactive approach. Reactive maintenance is very high risk. Costs can quickly soar when unexpected downtime takes your operations offline and brings production to a sudden halt. In fact, unplanned downtime costs manufacturers millions of dollars per year in lost productivity.

Furthermore, failing to keep up with regular preventative maintenance will accelerate wear and tear on the machine, reducing its useable lifespan. This means you'll need to replace equipment much more frequently, incurring unnecessary capital expenses.



Preventive Maintenance (PM)

Preventive maintenance, or PM, is a cost-efficient maintenance strategy intended to reduce downtime and extend the lifespan of all machinery. Much like annual or mileage-based service on consumer vehicles, preventative maintenance is often time or usage-based, following your equipment manufacturers' recommended schedule and servicing machines during planned maintenance visits.

While this time-tested approach is effective, it still has limitations. For example, with preventative maintenance, parts may be replaced unnecessarily when they are still in good repair. In contrast, issues can arise between planned maintenance visits that could lead to costly unplanned downtime.

For many organizations, PM is ideal for preserving low to medium-priority assets that are more expensive to repair.

How Preventive Maintenance Works

Also called planned or preventative maintenance, PM is conducted throughout an asset's normal operating conditions. This helps avoid unexpected breakdowns and their pricey consequences, such as unplanned downtime.

Preventive maintenance is not based on a machine's condition. Instead, it is based on recommendations from the asset manufacturer or on the average life cycle of an asset. Basing maintenance on a calendar means that some maintenance tasks are done when they aren't strictly needed. It also means that teams can ensure that they have the budget, inventory, and scheduling to perform the tasks.

Preventive maintenance software, including a computerized maintenance management system (CMMS), can simplify preventive maintenance even more through features such as auto-scheduled work orders. Streamlining maintenance practices reduces emergency, reactive work and increases worker safety and efficiency.

Performed consistently, preventive maintenance services, also called preventative maintenance services, can help your organization avoid expensive downtime and disruptions.

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Types of Preventive Maintenance

1 Calendar or Time-Based Preventive Maintenance

These types of preventive maintenance are completed at regular or scheduled intervals with help from preventive maintenance software. While all critical equipment should have PM, regularly checking equipment critical to production will help decrease breakdowns.

A motor-pool may have required fleet maintenance every 4 months. This is a great example of preventive maintenance

2 Usage-Based Preventive Maintenance

Another type of preventive maintenance example is called usage-based, where a machine's statistics are used to determine corrective actions. Usage statistics can include cycle counts, runtime, miles/kilometers traveled, or hours, among others.

For example, one kind of PM could be where an industrial maintenance technician checks machine usage statistics. Then, depending on measurements and usage readings gathered in rounds, maintenance may be scheduled.

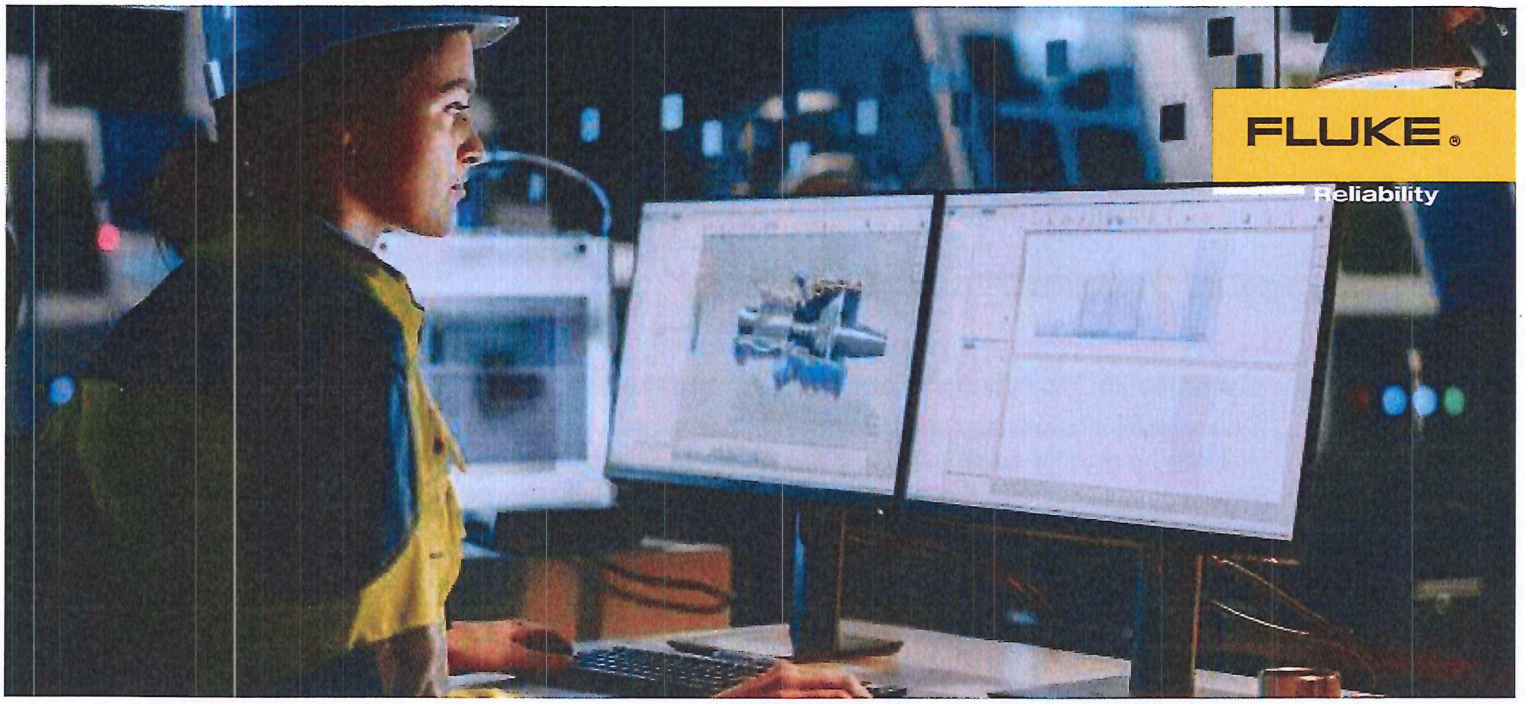
Advantages of Preventive Maintenance

Increase Asset Lifespan

A longer asset lifespan is a major advantage of preventive maintenance because it detects minor defects that throw a wrench into machine capacity. Maintaining good asset health assures that you have a shorter mean time between failures (MTBF). This KPI lends a hand in you making informed decisions for the next steps, instead of panicking about emergency work orders. It saves you the trouble of replacing expensive pieces and sets the precedent for ongoing regulatory compliance.

Save Money

Maintenance costs can put financial stress on the infrastructure, especially if there are complex mechanical systems in multiple buildings. To bring down asset spending, preventive maintenance lets technicians organize a larger number of tasks and complete them with more accuracy. For cleaning, it could show signs of leaks or rust accumulation on metal surfaces. And for the spare parts inventory, you won't need to purchase stock as often to handle a complete replacement.



Reduce Disruptions

Another advantage is lessening interruptions on integral workflows. Rather than halting production when fulfilling requests, you should schedule maintenance around expected downtimes to optimize equipment availability. To conserve resources, have each technician focus on one project while giving them access to the required assets. Plan accordingly by identifying the failure mode and assigning employees with matching skills to quickly finish the work order.

Regulate Asset Runtimes

Organizing a floor plan means needing to estimate how long assets will run and making sure machines don't fall out of their specifications. This is crucial for modifying the rate of production in case of rust build-up, uneven heat transfer, friction between surfaces, and other factors. Regular maintenance puts a stop to this by saving energy at the factory and generating less scrap or waste. The outcome is fewer faulty and damaged products reaching the consumer.

Reduce Equipment Downtime

Lastly, preventive maintenance minimizes overall downtime because your technicians don't have to shut everything down just to conduct a maintenance session. Compared to reactive measures, you aren't facing downtime from having to ship items or waiting for a specialist to arrive on-site. Instead, it gives you an opening to schedule activities after operations have ceased for the day. PM singles out areas that need attention, so you don't have to bring backup assets to pick up the slack. For more information, learn how to optimize and improve a preventive maintenance program.

Disadvantages of Preventive Maintenance

It involves extensive planned downtime

You need to schedule frequent shutdowns to give your maintenance team access to equipment, so that they can perform routine cleaning and repairs. Because shutdowns are based on a time- or usage-driven schedule, machines are taken offline for maintenance whether or not they actually require any repairs. This is great for getting ahead of potential issues, but when every minute of downtime is costly, shutting down equipment unnecessarily is not ideal.

It can be expensive

Your maintenance team will be changing parts and performing minor repairs on a regular basis, even when your equipment is already in optimal condition. This results in high costs, both in terms of labor and materials. Plus, you'll need to keep a lot of extra supplies on-hand, increasing costs and taking up valuable warehouse space.

It isn't tailored to your plant's needs

Preventive maintenance follows industry guidelines and standards for maintaining equipment. But those standards might not apply to the realities of conditions in your plant. Temperature, air quality, and other operating conditions can impact the lifecycle of all your assets. Preventive maintenance doesn't take these real-world conditions into account. Without additional data to support your maintenance timelines, you could end up performing unnecessary maintenance and you risk missing defects that can occur between scheduled maintenance visits.

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Predictive Maintenance (PdM)

Predictive maintenance, or PdM, is designed to predict failure trends via condition monitoring and machine learning algorithms that use a model to fine-tune the allocation of physical resources.

Furthermore, PdM enables teams to identify maintenance concerns in real-time rather than waiting until a scheduled maintenance visit or an unexpected machine failure. Condition-monitoring technology will instantly alert staff to potential problem so they can be fixed before they escalate.

With a predictive maintenance strategy, organizations can significantly reduce unplanned downtime, optimize their maintenance schedules, and resolve small issues before they escalate, saving significant costs over time. While predictive maintenance does require a technology investment, the return on investment (ROI) for this strategy are quickly realized.

Industrial PdM can be used for all equipment, or it can be reserved for your most critical assets. Backed by sensor information, this cost-saving strategy eliminates the guesswork inherent in reactive and preventative maintenance strategies.

How Does Predictive Maintenance Work?

Predictive maintenance directly monitors equipment performance and condition during normal operation. When a maintenance team knows the condition of every asset in real time, it reduces the chances of failures. Once identified, a predicted failure can be prevented.

Predictive maintenance technologies such as sensors and CMMS software are used to monitor real-time data on asset condition, preventing failures before they occur.

Condition monitoring sensors are installed directly on assets and capture performance data. A number of factors can be measured, such as vibration or temperature, depending on the asset. The sensors can detect issues such as pressure leaks, vibration abnormalities, or unusual voltage.

Cloud technology enables condition monitoring sensors to share the data they collect. Paired with the right predictive maintenance software, alarms and work orders can be triggered when asset conditions surpass defined thresholds.

Data modeling, based on known machine behavior and failure modes, is used to spot issues before they escalate to failure.

What's the Difference Between Predictive Maintenance and Preventive Maintenance?

Preventive maintenance and predictive maintenance are different strategies. Preventive maintenance uses the expected life cycle of an asset to determine when to perform maintenance tasks. One common preventive maintenance example is changing a car's oil every three months or every 3,000 miles.

Predictive maintenance uses the actual operating condition of an asset to determine what steps to take and when.

Many of the best maintenance programs use a combination of both strategies. A preventive maintenance schedule, based on manufacturer recommendations, is straightforward and sufficient for some assets. Other assets can even be run to failure. A predictive maintenance strategy can save both time and money, but it is more complex to implement.

While equipment is operating normally, it can be monitored by condition monitoring devices, like remote sensors. They can take measurements at regular intervals or continuously. These devices, paired with predictive maintenance software, can alert maintenance teams when any asset's condition changes. Automatically generated work orders enable teams to act quickly, preventing equipment failures.

Asset condition data can be trended and analyzed to help maintenance teams spot patterns and make more informed decisions. Ultimately, the goal of predictive maintenance is to maximize asset availability and minimize the time and cost spent repairing each asset.

When to Use Predictive Maintenance Techniques

Predictive maintenance is not necessarily the most effective strategy for every asset. Some assets can be run to failure with little to no impact on production or the bottom line. Others benefit from simple and straightforward preventive maintenance. But for some assets, predictive maintenance is the best strategy.

There are a few questions to keep in mind for each asset when considering creating a predictive maintenance plan:

- If this asset fails, how is production impacted?
- How much does it cost to repair this asset?
- How much does it cost to replace this asset?

Answering these questions for each piece of equipment can help teams start to focus their attention and resources.

How to Create a Predictive Maintenance Program

There are several key steps required to successfully create a predictive maintenance program.

1. Identify which assets should be targeted for predictive maintenance
2. Choose the predictive maintenance tools and methods you will use to monitor asset condition
3. Select and train an implementation team to learn and carry out predictive maintenance techniques
4. Perform system integrations to get a complete picture of asset health
5. Coordinate your overall maintenance strategy, identifying which approach will be used and where
6. Determine how asset health data will be shared among team members, stakeholders, and auditors
7. Implementing a predictive maintenance program requires taking a long-term view of your organization's goals and needs.

Reliability-Centered Maintenance (RCM)

Reliability-Centered Maintenance, or RCM, responds to non-linear failures by providing analytics on all potential failure modes and building a custom plan to address each part's stability. RCM aims to make equipment available at all times, no matter what degree of criticality it has.

This framework is quite elaborate, so many organizations find that they need to work with a reputable partner to integrate RCM across their entire network of assets. Otherwise, the company could end up with too many plans and no idea of how to execute them successfully.

The 4 Basic Principles of a Reliability-Centered Maintenance Program

A successful Reliability-Centered Maintenance program:

1. Is scoped and structured to preserve system function
2. Identifies failure modes — that is, the ways something might fail (failures are any errors or defects, especially ones that affect the customer, and can be potential or actual)
3. Addresses failure modes by importance
4. Defines applicable maintenance task candidates and selects the most effective one in the case of important failure modes

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How Do You Implement a Reliability-Centered Maintenance Program?

There are three phases of a Reliability Centered Maintenance program and seven steps within these phases to ensure the program is fully implemented. The three phases are Decision, Analysis, and Action.

Phase I: Decision

Justification and planning based on need, readiness, and desired outcomes.

1 Analysis Preparation

Reliability Centered Maintenance analysis is only as effective as the team behind it. The most effective cross-functional teams include maintenance employees, project leaders, subject matter experts, and even executive leadership.

Additionally, documenting procedures and your project plan can be vital to keeping your team on track. The beginning of an RCM project is a great time to outline your organizational goals, project management concerns, budget and timeline, and potential obstacles.

2 Select Equipment for Reliability-Centered Maintenance Analysis

Equipment selected for RCM analysis should be critical to operations, subject to the cost of repair vs. cost to replace debate and included in previous spending on preventive maintenance. To select the best equipment for RCM analysis, answer these questions:

- Could failure be difficult to detect during normal operation and maintenance?
- Could failure affect safety?
- Could failure have a significant impact on operations?
- Could failure have a significant impact on spending?

3 Identify Functionality

Create a complete list of a piece of equipment's functionality, including as much data as possible. It is important to specify your desired asset performance levels, rather than actual performance, as it may reflect an operational or maintenance issue. System functionality drives the required functions of the equipment supporting the system functions.

Phase II: Analysis

Conduct the Reliability Centered Maintenance study in a way that provides a high-quality output.

4 Identify Functional Failures

Functional failure is the inability of an asset or system to meet acceptable standards of performance. Failures can encompass poor performance, over performance, performing unnecessary or unintended functions, or complete failure. For example, when a motor bearing is failing because of a lack of lubrication, a Total Functional Failure would be the motor not rotating and the motor failing to function.

5 Identify and Evaluate the Effects of Failures

Next, your team should document what actually happens when failures occur. What can be observed? What is the impact of the failure on production? Is there a significant safety impact?

6 Identify Functionality

Once you identify your equipment and systematic functional failures, failure modes must be considered. One of the most common techniques to approach discovering failure modes is Failure Mode and Effects Analysis (FMEA). FMEA is a step-by-step approach for identifying all possible failures in a design, a manufacturing or assembly process, or a product or service. Understanding the effects of failure involves asking questions such as:

- What are the safety concerns with this failure?
- What impact does this failure have on operation/production?
- Does this failure mode result in full or partial outages?

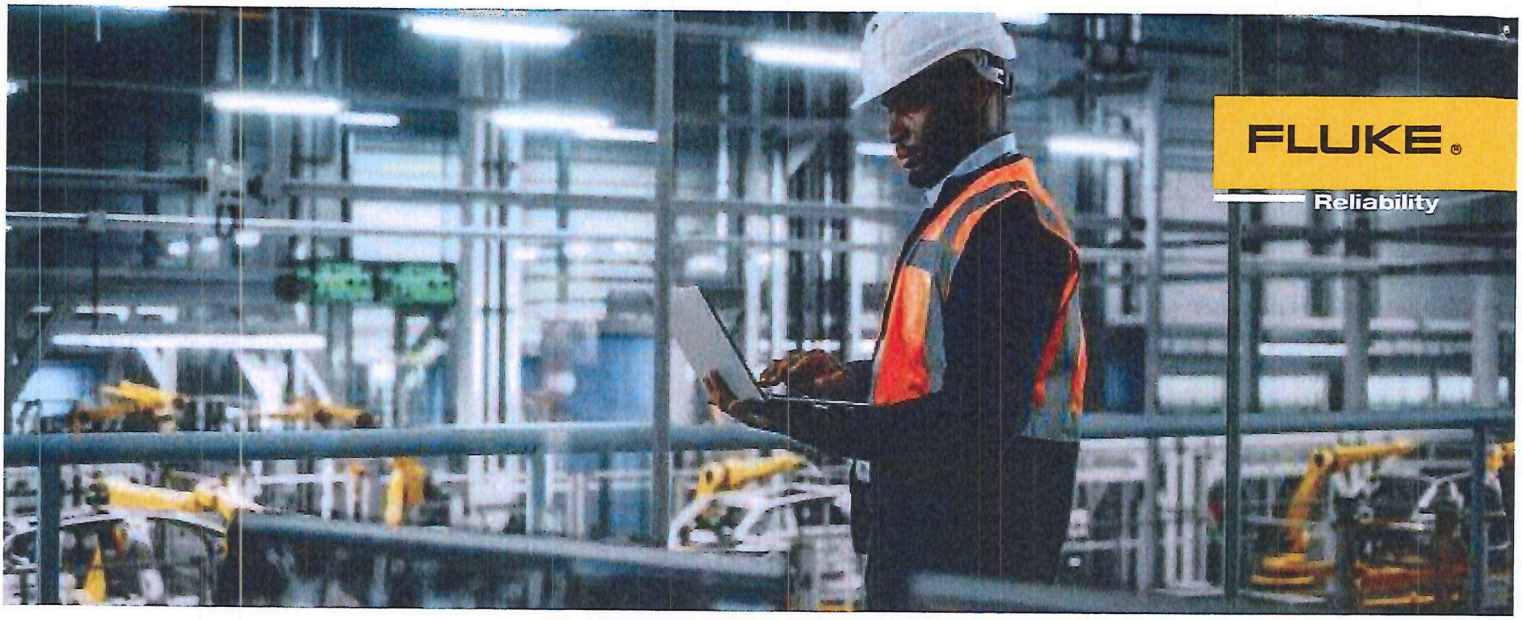
Phase III: Act

Act on the study's recommendations to update asset and maintenance systems, procedures, and design improvements.

7 Select Maintenance Tasks

At this point, the most appropriate maintenance action can be identified based on the failure mode information. Failure management techniques can be grouped into two categories:

- **Proactive tasks:** Preventive and predictive maintenance techniques are performed to prevent failure of a piece of equipment or system.
- **Default actions:** Reactive maintenance, where equipment is run until it fails, and then work is performed.



Choosing the Best Maintenance Strategy

What is the best strategy for managing your maintenance and reliability program?

There is no one-size fits all strategy.

When choosing a maintenance strategy, it is important to understand you budget, goals, and risk tolerance. Developing a robust maintenance strategy requires weighing the benefits and costs it brings to the table. Maintenance management is about tackling asset failure using the best criticality insights to eventually achieve the desired output.

For most operations, a mixture of predictive maintenance and preventive maintenance is key to keeping your assets running smoothly and to maximizing uptime. Predictive maintenance counters the disadvantages of preventive maintenance, but it doesn't mean the two strategies can't work in harmony.

Keep in mind that while a proactive maintenance strategy might cost more in terms of initial investment, it will often easily pay for itself the first time unplanned downtime is averted.

If you're interested in trying out a predictive maintenance strategy, start by testing out that approach on a few of your assets. Doing a test-run keeps your initial costs low and enables you to prove the value of predictive maintenance before scaling the approach across all of your assets.

Key to any proactive maintenance strategy, from preventive to predictive and reliability centered, is a software where you can manage, organize, and plan your maintenance activities – a Computerized Maintenance Management Software (CMMS).

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Choosing the Best CMMS for Your Maintenance Strategy

A Computerized Maintenance Management System (CMMS) software provides comprehensive oversight of what matters most for maintenance teams. The best CMMS software includes features like managing work orders and parts inventory, automating predictive maintenance activities, enabling proactive maintenance strategies, documenting maintenance activities for compliance, and much more.

Investing in the best CMMS software for your organization can not only keep your operations running smoothly but also help you optimize your efficiency and productivity. However, it's important to keep in mind that choosing the ideal software for your team is not just about the features and benefits – it's about finding a solution and a vendor that works for you and your team.

Choosing the right CMMS can be a difficult process. An estimated 80% of CMMS implementations fail to meet expectations due to lack of training and support after the sale. A trusted CMMS partner that provides the post-sale support you need can help you avoid common pitfalls and reap the full benefits of a robust CMMS solution.

Here's how to choose the best CMMS for your business needs.

Evaluate Which CMMS is Best for Your Team

Whether you are looking for a CMMS software for a small operation or a large enterprise, it is important to choose a CMMS solution that is flexible and scalable to your needs.

For large, multi-site operations, your maintenance team may be in search of a sophisticated and configurable system that can handle a high level of complexity and that can integrate seamlessly with a complex infrastructure of existing systems, from ERP software to SCADA systems. You may also need broad multi-language capabilities and localization features.

Meanwhile, smaller teams may require a simpler solution with a priority on software that is easy to use and quick to get off the ground. And if your company plans to expand, you want a CMMS that can accommodate the growth.

Ultimately, the best CMMS for you is one that can be configured to fit your unique requirements now – and grow with you into the future.

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Articulate Your CMMS Goals and Priorities

When assessing the best CMMS software for your maintenance operations, you first need to articulate your maintenance goals and priorities to determine whether a CMMS is right for your team. For example, consider the following questions:

- What are the short and long-term goals for your maintenance team?
- What is your biggest challenge or hurdle keeping you from achieving these goals?
- What KPIs matter most to your team?
- What maintenance strategy are you currently using, and how do you hope to evolve your maintenance strategy in the future?
- What's working well and what's not working well in your current maintenance strategy?
- If you have a CMMS already, why isn't it the best CMMS for your team?
- What training and implementation resources will you need?
- Do you also need professional services from your CMMS vendor? If yes, what kind of services?

4 Key Features to Look For in a CMMS

The purpose of a CMMS is to help drive your business forward, bringing your maintenance team to new levels of efficiency and productivity while reducing unexpected costs and downtime. While there are many critical features that support these objectives, there are four must-haves for the CMMS implementation:

1 **Configurability**

There's no one way to manage your maintenance operations. Every industry, company, and maintenance team has individualized needs. The best CMMS software is flexible to meet your unique requirements and scale with you over time.

2 **Training and Professional Services**

As mentioned previously, not having the right training and support is the #1 reason that CMMS implementations fail. Choosing a robust and flexible CMMS to your exact business requirements is ultimately meaningless if the implementation can't get off the ground and the solution is not used to its potential.

Find a partner that will provide the support you need both before and after the sale with training, implementation support, and long-term professional services to keep your maintenance operations moving in the right direction.

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3 Ease of Use

For any maintenance software, ease of use is key, especially for a software meant to make your job easier. Navigation should be simple and intuitive, requiring minimal keystrokes. It should be easy to both enter data into the system and extract meaningful insights from that data.

4 Mobile CMMS / Work Order Software App

Maintenance operations are now driven by real-time, actionable insights. The only way to capitalize on this is with a solution that brings these insights to your team's fingertips no matter where they are located. The best CMMS software has strong mobile CMMS capabilities, including a best-in-class work order software app.

Choosing the Best CMMS Software for Your Maintenance Strategy

Now that you are informed on what makes a great CMMS, take into account both your current maintenance strategy and the maintenance strategy you want for your program going forward.

How will this CMMS evolve your maintenance practices, taking you further into proactive approaches, while supporting your unique mix of different strategies for your specific assets and systems?

Make sure to ask yourself the following questions when making a decision on the CMMS that will be best for your long-term strategy and goals:

- Is it configurable and scalable enough to meet your business requirements now and in the future?
- Does it provide the four must-have capabilities described above?
- Does the vendor provide the support that you need to be successful in the long run?

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Chapter 3
Understanding Maintenance

"Your system is perfectly designed to give you the results that you get"

- - W. Edwards Deming

Chapter 3 Understanding Maintenance

3.1 Introduction
3.2 Key Terms and Definitions
3.3 Maintenance Approaches
3.4 Maintenance Practices: Others
3.5 Maintenance Management System: CMMS
3.6 Maintenance Quality
3.7 Maintenance Assessment and Improvement
3.8 Summary
3.9 Chapter Assessment
3.10 References and Suggested Reading

Chapter 3 Objectives

- Why do maintenance?
- The objective of maintenance
- Benefits of maintenance
- Types of maintenance approaches
- Purpose of CMMS/EAM
- Maintenance quality challenges
- Importance of assessing and improving your maintenance program regularly

Introduction

- Maintenance concerned with keeping an asset in good working condition so the asset may be used to its full productive capacity.
- Maintenance function includes:
  - Upkeep
  - Repairs

Definitions of Maintenance

- Simple Definition:
  - the work of keeping something in proper condition; upkeep.
- Broader Definitions:
  - Keep in "designed" or acceptable condition
  - Keep from losing partial or full functional capabilities
  - Preserve or protect

Maintenance Problems of the Past

Literature related to maintenance practices over past few decades indicates that most companies did not commit the necessary resources to maintain assets in proper working order.

- Assets were allowed to fail
- Then the necessary resources were committed to repair or replace failed assets or components

Maintenance Viewpoints of the Past

- Maintenance function was viewed as the necessary evil
- Therefore maintenance did not receive the attention it deserved

Things Are Changing

- In last few years, this practice has changed dramatically.
- Corporate world has begun recognizing the reality that maintenance does add value.
- Very encouraging to see maintenance moving from so-called "backroom" operations to the corporate board room

Things Are Changing – Case in Point

- 2006 annual report for Eastman Chemical included a couple of slides related to maintenance and reliability
- Stressing company's strategy of increasing equipment availability by committing adequate resources for maintenance.

New Paradigm of Maintenance

- Shift thinking to capacity assurance
- With proper maintenance, capacity of an asset can be realized at designed level
- Acceptable capacity level = target capacity level set by management (no more than the designed capacity)
- Management could justify increased maintenance cost by reducing downtime to increase capacity to design level

What Is Meant By a Maintenance Approach?

Maintenance Approaches

- Companies have many different approaches when it comes to their maintenance programs
- All approaches have at their basis the requirement to keep their facility's assets at whatever capacity level is necessary for their current operational needs

Maintenance Approaches (cont'd)

- Some of these maintenance programs are more structured than others (e.g., RCM analysis or annual/multi-year plan).
- The truth is that a company will have a maintenance program whether they admit it or not.
- Their program will simply be more costly than it has to be because they will live in a reactive maintenance state.

Why Have a Structured Maintenance Program?

1. Should improve production capacity
2. Should reduce overall facility costs

Structured Maintenance Program

- Reduces production downtime — the result of fewer asset failures
- Increases life expectancy of assets, thereby eliminating premature replacement of machinery and asset
- Provides more economical use of maintenance personnel
  - Due to working on a scheduled basis
  - Instead of unscheduled repair of failures
  - Also reduces overtime costs

Structured Maintenance Program (cont'd)

- Reduces cost of repairs by reducing secondary failures. When parts fail in service, they usually damage other parts
- Reduces product rejects, rework, and scrap due to better overall asset condition
- Identifies assets with excessive maintenance costs, indicating the need for corrective maintenance, operator training, or replacement of obsolete assets
- Improves safety and quality conditions

What Are Some Different Maintenance Approaches?

Basic Maintenance Philosophy (Approach)

Really only two-fold (one of two choices) for each asset:

Do some form of maintenance to prevent failure of an asset

OR

Allow asset to run-to-failure

Basic Maintenance Approaches

- Condition Based Maintenance (CBM) / Predictive Maintenance (PdM)
- Preventive Maintenance (PM)
- Proactive Maintenance
- Corrective Maintenance (CM) / Run-to-Failure (RTF)

  - *More details about each in subsequent chapters*

CBM/PdM Definitions

- CBM and PdM often used synonymously
- As seen by the similarity of their definitions:
  - CBM: Maintenance based on actual condition (health) of an asset as determined from non-invasive measurements and tests.
  - PdM: Maintenance based on actual condition (health) of an asset as determined from non-invasive measurements and tests. Condition measured using condition monitoring, statistical process control, or performance, or use of the human senses.

CBM/PdM Process

- Evaluates condition of assets by performing condition monitoring
  - Periodic route collection of asset health data
  - Continuous monitoring of asset health data
- Inspections mostly performed while the asset is operating, thereby minimizing disruption of normal system operations

CBM/PdM Process (cont'd)

"Predictive" component stems from goal of predicting the future trend of asset condition

- Using principles of statistical process control, trend analysis, and preselected thresholds
- To determine at what point in the future maintenance activities should be scheduled
- Allowing corrective actions to be optimized through proactive planning and scheduling
- Allowing preventive actions to be optimized by avoiding traditional calendar or run-time directed schedules

Multiple Condition Data Methods

- Vibration analysis
- Oil analysis
- Infrared (IR) thermography
- Ultrasonic — airborne, contact, etc.
- Electrical — motor, resistance, etc.
- Partial discharge and Corona detection Shock Pulse Method (SPM)
- Operational performance data — pressure, temperature, flow rates, etc.

The Challenges of CBM/PdM

- Starting a full-blown program utilizing all these technologies can be quite expensive
  - Test equipment for these different technologies
  - Training personnel to use this equipment and the technologies themselves
  - Choose for most "bang for your buck"
  - Reason to have RCM-basis for choosing where to apply each technology
- How the CBM/PdM team is organized
  - Centralized, dedicated team good way to start
  - Helps in standardizing methods and practices

Overcoming CBM/PdM Challenges

Requires firm management and organizational commitment to make program work

- Continue to push forward with financial and organizational investment
- Support proactive repairs and scheduled downtime in a timely manner

Ultimate Goal of CBM/PdM

- To identify proactive maintenance actions when:
  - Maintenance activity is most cost-effective
  - Before asset fails in service
- Adoption can result in substantial cost savings and higher system reliability:
  - Reduction in maintenance costs: 15–30%
  - Reduction in downtime: 20–40%
  - Increase in production: 15–25%

PM Definition

Maintenance at a fixed interval for inspection, component replacement, and/or overhauling

- Regardless of current condition
- Usually scheduled inspections performed to assess the condition of an asset
- Replacing service items, e.g., filters; oils, and belts and lubricating parts are a few examples of PM tasks
- May require another work order to repair other discrepancies found during PM

PM Process

- Maintenance or operations personnel regularly visit assets to assess its condition
  - Based on calendar time
  - Based on asset runtime
  - Based on asset cycles
- Checklists and procedures with task details can be helpful
  - Indicating what to check or what data to take
  - Document abnormalities other findings
  - Should be corrected before developing into failures

Goals of Performing PM

- Next best thing to CBM/PdM
- Maybe only approach with certain types of failures and/or specific equipment
- Regulatory requirements may force some level of PM
- Basic objective: To take a look at asset to determine if any telltale signs of failure or imminent failure
- If abnormalities are not corrected before they turn into failures, the PM program does not add any value

Proactive Maintenance

Three different definitions exist in industry:

Any maintenance work that has been identified in advance, planned, and scheduled

OR

All maintenance work completed to avoid failures or to identify defects that could lead to finding failures, including PdM and PM

OR

Only those tasks that are generated based on what is found during CBM and PM tasks

Corrective Maintenance (CM)

- CM is an action initiated as a result of an asset's observed or measured condition before or after functional failure.
- CM is also called Repair Maintenance
  - Because it corrects deficiencies
  - Because it allows the asset to work again after it has failed or stopped working
- Corrective Maintenance can be:
  - Scheduled Repairs
  - Major Repairs/Projects
  - Reactive Repairs (Breakdown)

What Is Meant by a Failure?

- Definition of Failure: Loss of an asset's ability to perform its required function; does not require asset to be inoperable; could also mean reduced speed or missing operational or quality requirements.
- When asset breaks down, it fails to perform its intended function and disrupts scheduled operation.
- This functional loss (partial or total) may result in defective parts, speed reduction, reduced output, and unsafe conditions.
- Function-disruption or reduction failures not given due attention will soon develop into asset stoppage.

Run-to-Failure

- Given the discussion thus far, why would I ever choose run-to-failure?
  - When analysis has been performed indicating the most cost-effective strategy to be run-to-failure
  - Because the total cost of maintenance is less than the corrective maintenance necessary for this run-to-failure strategy
  - Assuming that there is no safety impact to this run-to-failure strategy
- This should be a proactive decision of the organization for only those assets selected
  - NOT an overall organizational approach!

What Are Maintenance Practices?

Maintenance Practices

- Maintenance practice is a specific approach, not of the overall maintenance program, but of the way this program is executed
- Example maintenance practices:
  - Operator/Maintainer relationships/involvement
  - Procedures and task instructions
  - Cleaning and lubricating
  - Planning and scheduling
  - Skills development and training
  - Analysis tools and techniques
  - Designing for Reliability and Maintenance

Operator Involvement Practice

- Operator-Based Maintenance (OBM or TPM)
- Foundation piece of TPM philosophy
- Operators are the first line of defense
- Main objective is to equip operators with:
  - Ability to detect abnormalities
  - Ability to correct minor abnormalities and restore function, if they have the ability
  - Ability to set optimal asset conditions
  - Ability to maintain optimal equipment conditions

What Is a CMMS?

CMMS

CMMS: Computerized Maintenance Management System (software)

- Software system that keeps record and tracks all maintenances activities; usually integrated with support systems such as inventory control, purchasing, accounting, manufacturing, and controls maintenance and warehouse activities.
- Other similar electronic systems
  - EAM : Enterprise Asset Management
  - ERP: Enterprise Resource Management
- Many different software vendors available

CMMS Capabilities

- Many different capabilities exist, dependent on software vendor
- Only few of the capabilities listed below:

Assets	Work Orders	PMs
Job Plans	Crew Schedules	Reports
Reliability Analysis	Configuration Management	Inventory / Spares
Work routing	Work Backlog	Material

Many more capabilities listed in book

Barriers to CMMS Acquisition

- Organization is too small for a CMMS
- CMMS project payback or savings inadequate
- MIS or IT doesn't give CMMS high enough priority
- MIS and maintenance speak different technology languages
- Participants fail to reach consensus

Why So Many CMMS Projects Fail

- Selecting wrong CMMS system for your business
- Employee turnover
- Lack of adequate training during implementation
- Employee resistance
- Being locked into restrictive hardware/software
- Inadequate supplier support for the CMMS
- High expectations and quick return on investment
- Internal Politics — Financial or IT — heads the CMMS/EAM implementation team

NOTE: CMMS projects should be led by senior maintenance /reliability management person

Selecting the "Right" CMMS

Selecting the "right" CMMS is crucial to successful implementation

- Depends upon multiple things:
  - System Features
  - Ease of Use
  - System Affordability
  - Vendor Support

What Is Meant By Maintenance Quality?

Maintenance Quality

- It is said that "Accidents do not happen, they are caused."
  - The same is true for asset failure.
  - Assets fail due to basically two reasons: poor design and human error.
- All maintenance work involves some risk.
  - Risk refers to potential for inducing various defects while performing maintenance tasks.
  - Human errors made during the PM, CBM, and CM tasks eventually may lead to additional failures from maintenance performed.

Poor Maintenance Quality Examples

During a PM task you may cause damage during inspection, repair adjustment, or installation of replacement part by:

- Installing material/ part that is defective
- Incorrectly installing a replacement part, or incorrectly reassembling
- Reintroducing infant mortality by installing new parts which have not been tested
- Causing damage to an adjacent asset or component during a maintenance task

Improving Maintenance Quality

To create high quality and motivated personnel, try the following measures:

- Provide training in best practices and procedures for specific assets.
- Provide appropriate tools to perform tasks effectively.
- Get involved in performing FMEA/RCA/RCFA, and in developing maintenance procedures.
- Follow up to assure quality performance and to show that management cares for quality work.
- Publicize reduced costs with improved uptime, the result of effective maintenance practices.

Why Would We Assess Our Maintenance Program?

Maintenance KPIs

- KPI: Key Performance Indicator
- KPIs (also called metrics) are an important management tool to measure performance (to assess our maintenance program)
  - "What gets measured gets done."
- KPIs also help us make improvement actions
  - "If we can't measure it, we can't improve it."
- However, too much emphasis on KPIs, including the wrong KPIs, not right approach
  - Selected indicators shouldn't be easy to manipulate just to "feel good."

Maintenance KPI Selection

The following criteria are recommended for selecting the best KPIs:

- Should encourage the right behavior
- Should be difficult to manipulate
- Should be easy to measure — data collection and reporting

Example Maintenance KPIs and Their Benchmark Values

Metric	Typical	World Class
Maintenance Cost % of ERV	3 - 9 %	2.5 - 3.5 %
Production Loss - Breakdowns	5 - 10 %	< 1 %
Reactive - CM Unscheduled	40 - 55 %	< 10 %
Planned Maintenance	40 - 70 %	85 - 90 %
Overtime	10 - 20 %	< 5 %
Rework - Maintenance Quality	~ 10 %	< 1 %

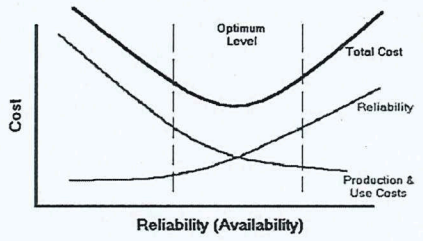
How Can We Improve Our Maintenance Program?

Maintenance Improvement

Maintenance effectiveness can be improved

- By optimizing the maintenance work tasks
  - These tasks can be optimized by using tools and techniques such as FMEA, RCM, and predictive technologies
- By effective task execution through the utilization of the many tools available
  - These tools and techniques can help optimize the content of the work tasks to be accomplished.

Finding the "Sweet Spot" of Maintenance



Finding the Sweet Spot

- Maintenance Cost Change =
  [Proposed Maint Cost] – [Current Maint Cost]
- Profit Change = [Profit Per Unit] x [Production Change]
- Production Change =
  [Proposed Production] – [Current Production]
- Production =
  [Production Per Hour] x [Actual Production Hours]
- Actual Production Hours =
  [Available Production Hours] x [% Uptime]
- Available Production Hours =
  [Max Production Hours] – [Scheduled Downtime Hours]

Create a "Living Maintenance Program"

- Continually review processes, procedures, and tasks for applicability, effectiveness, and interval frequency
- Standardize procedures and maintain consistency
- Identify and execute mandated tasks to ensure regulatory compliance
- Apply and integrate new predictive technologies
- Ensure task instructions cover lockout / tag out procedures and all safety requirements
- Ensure operation and maintenance personnel understand importance of PM practice and provide feedback for improving PMs

Summary

- Maintenance has recently shifted from merely maintaining and repairing assets to a new paradigm of capacity assurance.
- Benefits of a structured maintenance program are improving production capacity and reducing overall facility costs.
- Maintenance can use multiple approaches:
  - Condition Based/Predictive Maintenance
  - Preventive Maintenance
  - Proactive Maintenance
  - Corrective Maintenance / Run-to-Failure

Summary (cont'd)

- Multiple best maintenance practices can be used, including operator-based maintenance.
- A CMMS is an important tool to support maintenance activities.
- Another important piece of a maintenance program should be to assess and improve your maintenance program continuously.

3.9 Chapter Self -Assessment Questions

1. Define maintenance and its role.
2. What are the different categories of maintenance work?
3. What can equipment operators do to support maintenance?
4. Why would an organization support operators getting involved in maintenance?
5. Why would an organization need to have a CMMS? What is the difference between a CMMS and an EAM?
6. List five maintenance metrics and discuss why they are important.
7. Name five PdM technologies and discuss how they can help reduce maintenance costs.
8. Define Proactive Maintenance
9. What are the benefits of a structured maintenance program?
10. How can a CMMS/EAM system help improves maintenance productivity?

Chapter 3 Comprehension Assessment Questions

1. What new name can be given to maintenance function? Discuss the benefits of name selected
2. Based on the following information, calculate the improved capacity from maintenance improvements.
   Consider an asset with production capacity of 100 units per hour with its product demand able to handle all the units that could be produced. Each unit adds additional profit of $5 per unit. The current maintenance program for this asset requires scheduled downtime of 500 hours per year at a cost of $25K, yielding 80% asset uptime. With a change in maintenance approach, the asset will require 600 hours of downtime per year at a cost of $50K (including labor & additional equipment cost). This will increase asset uptime to 85%.
   Should the company make this improvement to their maintenance program?
3. What does literature indicate about maintenance practices over the past few decades?
4. How was the maintenance function viewed in the past
5. What is the basis of all maintenance approaches?
6. What is the consequence of failing to perform maintenance activities?
7. What is the most important reason to have a structured maintenance program?
8. What is the goal of condition based maintenance (CBM)/predictive maintenance (PdM)?
9. At what point of during asset operation are CBM/PdM inspections typically performed?
10. What is a benefit of performing CBM/PdM inspections at the point of asset operation that they are performed? Minimizing disruption of normal system operation (p. 55)
11. What are the benefits of adoption of a CBM/PdM program in the maintenance of an asset?
12. What is the basic difference between a CBM/PdM and Preventive Maintenance (PM) program?
13. Give an example that shows the difference between a CBM/PdM and PM approach to maintenance.
14. What have past studies shown that a well implemented CBM/PdM program can provide as far as savings when compared to a traditional PM program?
15. What are the typical savings that you will see with a fully implemented CBM/PdM program when there is no good PM program in place?
16. What are some of the challenges of starting a full-blown CBM/PdM program utilizing all possible technologies?
17. What are two reasons why a PM approach would be the best maintenance approach?
18. Describe the basic approach when it comes to doing PM.
19. What are two different time-based approaches for a PM program?
20. When is it appropriate to select a run-to-failure strategy for an asset rather than a PM or CBM/PdM strategy?
21. What are the main objectives of a PM approach of maintenance?
22. Calculate the proactive maintenance ratio metric based on the following data.

Total Preventive Maintenance Cost	$250K
Total Condition Based Maintenance/ Predictive Maintenance Cost	$150K
Total Maintenance Cost Identified by PM & CBM/PdM	$400K
Total Corrective Maintenance Cost	$200K

23. What is the basic definition of corrective maintenance?
24. What are the three major classifications of corrective maintenance?
25. What are the potential outcomes of a functional failure?
26. What are some potential asset abnormalities that are indications of imminent trouble for asset?
27. At what point during operation has it been observed that a high percentage of failures are likely to occur?
28. What is the responsibility of operators with regard to maintenance?
29. What is the main objective of an Operator-Based Maintenance program?
30. What are the asset-related skills that are necessary for an Operator-Based Maintenance program to be successful?
31. What is TPM?
32. What are some maintenance skills that operators should be able to learn as part of maintenance skills training?
33. What are operators able to do using sensory tools to identify problem areas with assets?
34. What are suggested measures to help in achieving the goal of Total Productive Maintenance?
35. What are some maintenance issues that cleaning will allow easy identification of?
36. What are some potential lubrication issues?
37. List at least 10 capabilities that a CMMS system should perform.
38. What are the major features the work order management module of a CMMS should include?
39. What are some examples of customization capability for a CMMS?
40. What are the benefits of tracking life cycle costs of assets?
41. What is the one of the more important trends being adopted into the CMS industry?
42. What are the typical barriers to CMMS acquisition?
43. What are the three major facets to be considered in selecting the right CMMS for your organization?
44. What are some of the reasons why a CMMS project may fail?
45. Who should ideally lead the CMMS implementation team?
46. What are the major steps that should be followed in deciding to acquire a CMMS?
47. What are the two basic reasons that assets fail?
48. Why are most asset failures deemed to be preventable?
49. What are some examples of damage that may occur due to human error during maintenance?

50. What measures are suggested to create high quality and motivated personnel?
51. What does the acronym KPI stand for?
52. What are two benefits of maintenance KPIs?
53. What criteria are recommended for selecting the best KPIs?
54. What are some key maintenance metrics and their associated benchmark data (typical findings and world-class values)?
55. How can maintenance effectiveness be improved?
56. What are the key elements that make up a living maintenance program?

Research Questions

(Always cite your references when answering research questions.)

1. Create a different categorical breakdown of maintenance activities than what is described in this chapter and discuss why this categorical breakdown is better, worse, or equivalent value in describing an organization's maintenance activities.
2. Describe a less commonly used CBM/PdM technology (including the estimate cost to implement this technology, how to use (or the process for using) this technology, the types of assets and failure modes for which the technology can be used, and the limitations of this technology).
3. Evaluate at least one expert's view of each of the three different definitions applied to the term "Proactive Maintenance" and then explain which definition you prefer and why.
4. Discuss why or when run-to-failure would be the most appropriate maintenance approach/strategy.
5. Describe a maintenance practice not covered in detail in this chapter and why this activity may or may not be more important than the one covered in detail in this chapter.
6. Explain why/when an organization should <u>not</u> use a CMMS.
7. Contrast two different CMMS/EAM packages; select which you think is the better of the two and explain why.
8. Compare the advantages, disadvantages, and potential challenges of implementing mobile technology for an organization's CMMS.
9. Explain why human error is or is not prevalent in maintenance activities using research outside this book.
10. Discuss ways that organizations are using to limit their risk with regard to human error in maintenance.
11. List key maintenance KPIs (at least 5) not discussed in the book and provide your information sources.
12. Evaluate at least three improvement processes/practices for improving a maintenance program.
13. Explain why many CMMS/EAM systems don't provide projected benefits?
14. Describe the quality issues in maintenance. Discuss what we could do to improve.

Chapter 6
Measuring and Designing for Reliability and Maintainability

Insanity is doing the same thing, over and over again and expecting different results

- Albert Einstein

Chapter 6: Measuring and Designing for Reliability and Maintainability

6.1 Introduction
6.2 key Terms and Definitions
6.3 Defining and Measuring Reliability and Other Terms
6.4 Designing and Building for Maintenance and Reliability
6.5 Summary
6.6 Self Assessment Questions
6.7 References and Suggested Reading

Chapter 6 Objectives

- Understand reliability and why it is important
- Calculate reliability, availability, and maintainability
- Measure and specify reliability
- Review design for reliability
- Explain the impact of O&M costs on an asset's life cycle cost

Introduction

- Asset reliability important focal point for many organizations
- Source of competitive advantage
- Central theme for maintenance departments
- Identifies the right work to be performed

Reliability Only One Piece

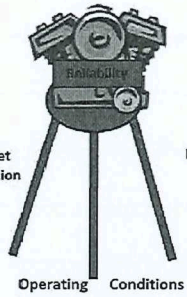
Reliability is design attribute considered when designed and installed

Designed-In Reliability

Maintenance Plan

Operating Environment

Reliability Also Has 3 Key Elements



Asset Function

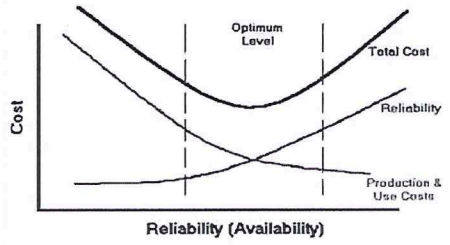
Mission Time

Operating Conditions

Maximizing Reliability

- One challenge in understanding reliability is belief of some that they need to absolutely maximize reliability
- 100% reliability often results in high acquisition and maintenance costs not a cost-effective, affordable strategy
- Best approach is to define asset or facility reliability requirements to support underlying business need

Optimizing Reliability



Why Reliability?

Reliability is important for several reasons:

- Customer satisfaction
- Reputation
- Operations & Maintenance (O&M) costs
- Repeat business
- Competitive advantage

The Costs of "Unreliability"

- There are costs of assets not being reliable ("unreliability")
- Loss of production or service not provided
- Lost customer confidence
  - May not buy product or service again
  - Inconvenience effect
  - Time wasted
- Cost to repair or replace components or entire asset

What Is RAM?

Reliability
Availability
Maintainability

Reliability Is Not RCM

For many, reliability is synonymous with Reliability-Centered Maintenance (RCM).

- But reliability is not RCM.
- RCM is a proactive methodology utilizing reliability principles for identifying the right work.
- RCM sustains reliability.

Reliability Is Not Maintenance

For others, reliability is synonymous with maintenance

- But reliability is not maintenance
- Maintenance is the act of maintaining or the actual work of keeping an asset in proper operating condition
- Maintenance also sustains reliability

Reliability Is Not Quality Control

For still others, reliability is synonymous with Quality Control (QC). But reliability is not QC.

- QC is concerned with how process is meeting specifications to guarantee consistent product quality.
- Thus QC is more of a snapshot of manufacturing process quality rather than reliability.
- QC works with reliability.

What Is Reliability?

- Reliability is a broad term focusing on an asset's ability to perform its intended function to support manufacturing, provide a service, or some other capability.
- MIL-STD-721C: "the probability that an item will perform its intended function for a specified interval understated conditions."
- Understanding the term and how it differs from maintenance is key to establishing a successful program for improving reliability for the long-term.

Inherent Reliability

- Assets are designed with a certain level of reliability based on effective use of reliable components and their configurations.
- Some components may work in series and others in parallel to provide the overall desired reliability.
- This is the inherent reliability.

Two Types of Assets

- Repairable assets (or components)
  - Can be repaired when they fail
  - Examples: compressors, hydraulics, pumps, motors, valves
  - Characterized by Mean Time Between Failures (MTBF)
- Non-repairable assets (or components)
  - Cannot be repaired – must replace when fails
  - Examples: light bulbs, rocket motors, circuit boards
  - Characterized by Mean Time to Failure (MTTF)

Mean Time Between Failures (MTBF)

$$MTBF = \frac{\sum \text{Operating Time}}{\#\text{Failures}}$$

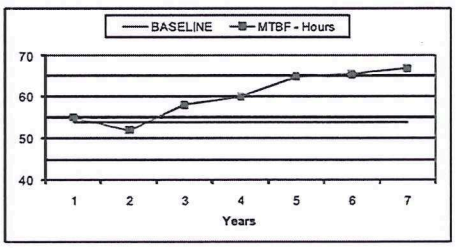
- MTBF is inverse of failure rate (λ)
- Higher MTBF is better

Mean Time to Failure (MTTF)

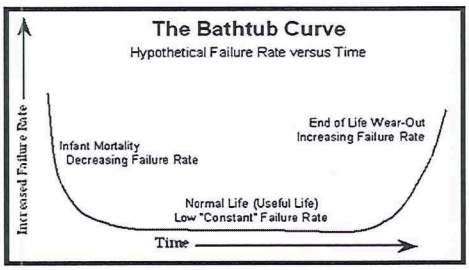
$$MTTF = \frac{\Sigma TimeToFailure}{\#Failures}$$

- Higher MTTF is better

Trending MTBF (and MTTF)

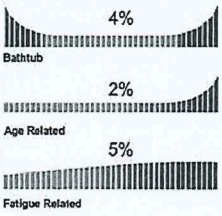


The Bathtub Curve

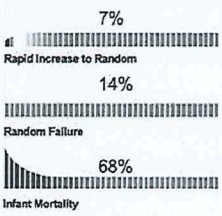


Failure Pattern / Distribution

<20% age related



>80% random



Calculating Reliability from MTBF

$$R = e^{-\lambda t}$$

OR

$$R = e^{-t\frac{1}{\text{MTBF}}}$$

*Recall that $\lambda = \frac{1}{\text{MTBF}}$

Calculating Required MTBF from Desired Reliability

- In order to reverse this equation, we simply take the natural log (ln) of both sides of the previous equation, which eventually translates to the following formula:

$$\text{MTBF} = -t\frac{1}{\ln(\text{Desired Reliability})}$$

Maintainability

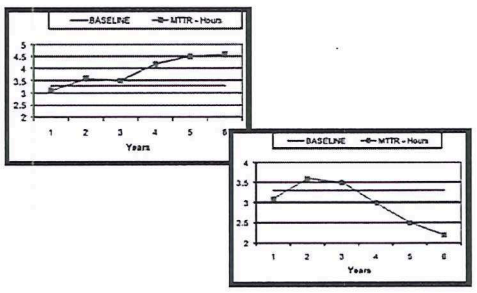
- Maintainability is a measure of an asset's ability to be restored to a specified condition when maintenance is performed by personnel having certain skills and using prescribed procedures and adequate resources
- Characterized by Mean Time to Repair (MTTR)

Mean Time to Repair (MTTR)

$$MTTR = \frac{\sum \text{Time To Repair}}{\#\text{Failures (Repairs)}}$$

- Some call it pure repair time (or wrench time).
- Others use Mean Downtime (MDT) to capture actual time asset is down.
- Lower MTTR is better.

Trending MTTR



Availability

- Availability is a function of reliability and maintainability.
- It is measured by the degree to which an asset or facility is operating at the start of the mission and for its duration when the asset or facility is needed

Different Types of Availability

- *Inherent Availability:* Classical definition determined by design
- *Achieved Availability:* Includes preventive maintenance but not delays
- *Operational Availability:* Considers preventive and corrective maintenance, including any delays

Availability

$$Availability = \frac{MTBF}{MTBF + MTTR}$$

OR

$$Availability = \frac{Uptime}{Uptime + Downtime}$$

Calculating RAM Example

A plant's air compressor system is operated for 1000 hours last year. The plant's CMMS system provided the following system data:

- Operating time = 1000 hours
- Number of failures, random = 10
- Total hours of repair time = 50 hours

What's the expected reliability and availability of this compressor system if we have to operate this unit for 100 hours?

Calculating RAM Example (cont'd)

$$MTBF = \frac{1000}{10} = 100$$

$$MTTR = \frac{50}{10} = 5$$

Calculating RAM Example (cont'd)

$$R = e^{-(100)\frac{1}{100}} = 0.37 = 37\%$$

$$Availability = \frac{100}{100+5} = 0.95 = 95\%$$

What If?

- What would the MTBF value have to be if the reliability needed was 75% in order to meet customer expectations?
- Based on the previously calculated MTBF value, what would the MTTR value have to be if the availability needed was 99% in order to meet customer expectations?

What If Example (cont'd)

$$MTBF = -(100)\frac{1}{\ln(0.75)}$$

$$MTBF = 347.6$$

- Let's check ourselves:

$$R = e^{-(100)\frac{1}{347.6}} = 0.75 = 75\%$$

What If Example (cont'd)

$$MTTR = \frac{MTBF}{Availability} - MTBF$$

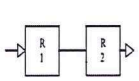
$$MTTR = \frac{347.8}{0.99} - 347.8 = 3.5$$

$$Availability = \frac{347.8}{347.8 + 3.5} = 99\%$$

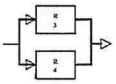
What Is Reliability Modeling?

Reliability Modeling

- Failure logic of assets, components, or even entire facilities can be shown in a Reliability Block Diagram (RBD).



Series Configuration

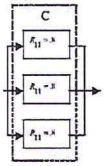


Parallel Configuration

Reliability Modeling

- Some failure logic in a Reliability Block Diagram (RBD) includes m – out – of –n that need to function.

m-out-of-n configuration



Calculating Series Reliability

$$R_{sys} = R_1 \times R_2 \times ... R_n$$

$$R_{sys} = e^{-t(\lambda_1 + \lambda_2 + ... + \lambda_n)}$$

Calculating Parallel Reliability

$$R_{sys} = 1 - (1 - R_3)(1 - R_4)...(1 - R_n)$$

OR

$$R_{sys} = 1 - (1 - e^{-t(\lambda_3)})$$

$$(1 - e^{-t(\lambda_4)})...(1 - e^{-t(\lambda_n)})$$

Calculating m-out-of-n Reliability

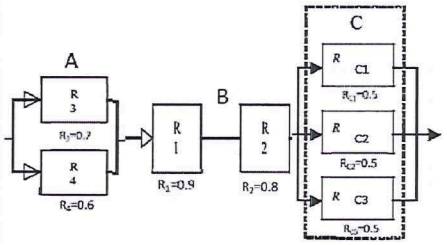
m - # of Working element	Overall System Reliability
1 out of 2 2 out of 2	$R^2 + 2R(1-R) = 1 - (1-R)^2$ R^2
1 out of 3 2 out of 3 3 out of 3	$R^3 + 3R^2(1-R) + 3R(1-R)^2 = 1 - (1-R)^3$ $R^3 + 3R^2(1-R)$ R^3
1 out of 4 2 out of 4 3 out of 4 4 out of 4	$R^4 + 4R^3(1-R) + 6R^2(1-R)^2 + 4R(1-R)^3 = 1 - (1-R)^4$ $R^4 + 4R^3(1-R) + 6R^2(1-R)^2$ $R^4 + 4R^3(1-R)$ R^4

Assumption: each element/component's reliability is same = R

Calculating System Reliability

- The real world isn't as simple as one series or parallel or m-out-of-n configuration.
- The real world is usually a combination of series, parallel, & m-out-of-n configurations.
- Therefore, the key to calculating system reliability with various configuration types is to first break the complex into simple.
  - Convert every parallel and m-out-of-n configuration into a single reliability value.
  - Then each of these single reliability values can be treated as a series group together.

Calculating System Reliability Example



Calculating System Reliability Example

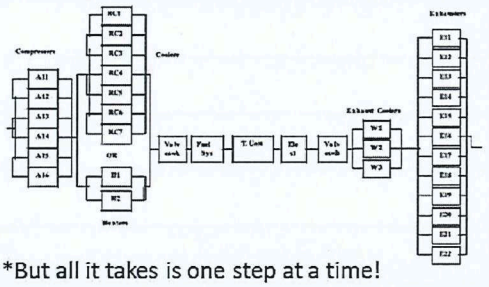
$$R_A = 1-(1-0.7)(1-0.6) = 0.88$$

$$R_B = (0.9)(0.8) = 0.72$$

$$R_C = (0.5)^3 + 3(0.5)^2(1-0.5) = 0.5$$

$$R_{ABC} = (0.94)(0.72)(0.5) = 0.32$$

And It Can Get Very Complicated



*But all it takes is one step at a time!

Reliability Modeling

- Then it can get too complicated to perform these calculations by hand.
- There are multiple software packages available to perform this modeling.
  - Input MTBF & MTTR values for each component.
  - Typically will assume exponential failure distribution.
  - But one can even input actual failure data if software package will create failure distributions (Weibull, etc.).

What Is Meant by Asset Life Cycle Cost (LCC)?

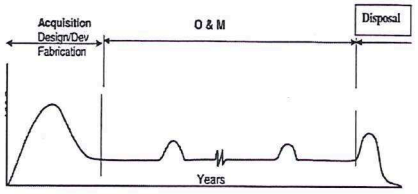
a) Reliability at 25 hr = 94.4%

b) MTBF: 434.8 hrs $Q_4(25) = 1 - e^{-(0.0005)\times(25)}$

$e^{-0.0125} = 0.9876$ $Q_4(25) = 1 - 0.9876 = 0.0124$

Asset Life Cycle Cost (LCC)

- Asset LCC are ALL costs expected during the life of the asset.



Asset Life Cycle Cost (LCC)

- ALL costs throughout the life of asset
- Acquisition
  - Design and Development
  - Demonstration and & Validation
  - Manufacturing/Assembly/Build/Installation
- Operations & Maintenance (O&M)
  - Operations (includes manpower, energy, supplies, etc.)
  - Maintenance (PM, CM, etc.)
- Disposal

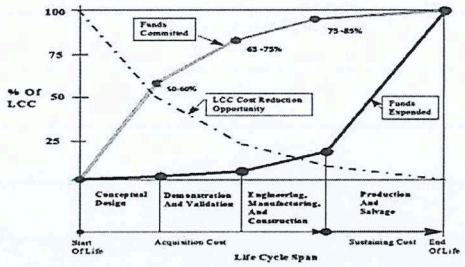
Distribution of Asset Life Cycle Cost (LCC)

For a Typical

	DoD System*	Industrial
Design and Development	10–20%	5–10%
Production / Fabrication / Installation	20–30%	10–20%
Operations and Maintenance (O&M)	50–70%	65–85%
Disposal	<5%	<5%

* Assurance Technologies Principles and Practices by Raheja & Allocco DoD –Department of Defense

But Distribution of Asset LCC Not the Same as Impact of Asset LCC



How Does One Design for RAM (Reliability, Availability, and Maintainability)?

Design for RAM

- RAM requirements and specifications
- Proper component selection and configuration
- Reviewing the design based on RAM
- Considering logistics support
- Planning in order to reduce O&M costs

RAM Requirements and Specs

- A reliable asset must have good reliability (RAM) requirements and specifications
- Should address:
  - Condition and environment asset will operate in, probability of successful performance, function to perform, mission time, usage limitations, skills needed for operators & maintainers
- Should be unambiguous since otherwise leaves great deal of room for error, which leads to poorly-understood design requirements

Other Good Ideas for RAM Specs

- Display asset performance/condition data (early warnings, diagnostic display, pinpoint problems)
- Use of modular and standardized components
- Use of redundant parts/components
- Minimize special tools — parts
- Operations and maintenance training material
- FMEA / RCM-based maintenance plan
- Maximizes use of CBM technologies
- Basis for spares recommendations
- Life Cycle Cost analysis
- O&M cost estimates

Good Example of RAM Requirements

There shall be a 90% probability (of success) that the cranking speed is more than 85 rpm after 10 seconds of cranking (mission) at –20 ^{0}F of (environment) for a period of 10 years or 100,000 miles (time). The reliability shall be demonstrated at 95% confidence.

"Assurance Technologies Principles and Practices by Raheja and Allocco"

*Additionally, see checklist on pp. 182-184 in the book

RAM Approach in Design

- As much as 60% failures and safety issues can be prevented by making changes in design
- Asset should be designed:
  - For fault tolerance
  - To fail safely
  - With early warning of failure to user
  - With built-in diagnostics to ID fault location
  - To eliminate all critical fail modes cost-effectively

RAM Analysis for Design

- Reliability Analysis
- Maintainability Analysis
- System Safety and Hazard Analysis
- Human Factors Engineering Analysis
- Logistics Analysis

How Do We Improve RAM?

How Do We Measure These Improvements Against Where We Currently Are?

Improving RAM

- After an asset is installed, reliability cannot be changed without redesign or replacement of better components.
- Maintainability can be improved with changes to training, planning and scheduling, logistics, available spares and materials, etc.
- Availability can be improved by repairing or replacing bad components before they fail with a good reliability-based (RCM) program
- Evaluating and finding ways to improve these is a key aspect of reliability engineering.

Designing for RAM Measures of Performance

- Reliability (MTBF, MTTF)
- Availability
- Maintainability (MTTR)
- Asset Life Cycle Cost (LCC)
- % Designs with RAM Requirements

Summary

- Improving reliability essential to the success of any organization, especially operations and maintenance groups
- Understanding reliability and its relation to maintenance in its reduction of overall asset life cycle costs (LCC)
  - O&M is ~80% of overall LCC
  - O&M costs are mostly determined during design
- Reliability should be designed-in and should be a strategic element of facility planning

Chapter 6 Self-Assessment Questions

1. Define reliability and maintainability.
2. What's the difference between maintenance and maintainability?
3. If an asset is operating at 70% reliability, what do we need to do to get 90% reliability? Assume assets will be required to operate for 100 hours.
4. If an asset has a failure rate of 0.001 failures/hour, what would be the reliability for 100 hours of operation?
5. What would be the availability of an asset if its failure rate is 0.0001 failures/hour and average repair time is 10 hours?
6. What would be the availability of a plant system if it is up for 100 hours and down for 10 hours?
7. If an asset's MTBF is 1000 hours and MTTR is 10 hours, what would be its availability and reliability for 100 hours of operation?
8. Define availability. What strategies can be used to improve it?
9. What is the impact of O&M cost on the total life cycle cost of an asset?
10. What approaches could we apply during the design phase of an asset to improve its reliability?

Q4.) $e^{-0.001 \times 100} = 0.9048$

$= 90.5\%$

Ch 6 Comprehension Assessment Questions / Answers

1. What is the difference between reliability and reliability centered maintenance (RCM)?
2. What is the relationship between RCM and PM?
3. What are three key elements of asset reliability?
4. What is the relationship between reliability and design?
5. What is the objective of maintainability?
6. What is required in order to improve reliability?
7. What is the downside of ensuring 100% reliability?
8. Draw the reliability/availability economics diagram.
9. What are the basic reasons that asset reliability should be considered important?
10. What are the two basic types of assets with regard to measuring and designing for reliability and maintainability?
11. What is the difference between MTTR and MDT?
12. Why would one say that MTBF and MTTR have reverse relationships?
13. What are the differences between inherent availability, operational availability, and achieved availability?
14. Describe what is meant by the bathtub curve.
15. Draw and give percentage of population values for the six basic failure patterns.
16. How much more likely is it to have a random failure than an age-related failure?
17. Calculate reliability and availability values based on the following information.
    A facility's critical piece of equipment is operated for 4500 hours last year. According to available data, this equipment had 15 failures with an average of 40 hours required to repair each failure. The facility manager would like to estimate the expected probability that this equipment can make it through a critical operation for 500 hours without a failure along with the expected availability for next year's operation.
18. Based on the previous data, what would it take to reach the facility manager's desired reliability value of 80%?
19. Assuming the desired reliability value was attained from the previous question, would this alone enable an availability value of 99%?
20. Calculate reliability and availability values based on the following information.
    A facility's emergency generator is operated for 250 hours last year. According to available data, this equipment had 5 failures with an average of 16 hours required to repair each failure. The facility manager would like to estimate the expected probability this equipment can make it through a typical downtime period (72 hours) without a failure along with the expected availability for next year's operation (estimated to be about the same as last year).
21. Based on the previous data, what would it take to reach the facility manager's desired reliability value of 80%?
22. Assuming the desired reliability value was attained from the previous question, would this alone enable an availability value of 95%?
23. Draw a reliability block diagram and calculate the overall system reliability for the following example.

The production line has 5 pieces of equipment that must all work in order to manufacture the product. These 5 pieces of equipment have reliability values of 0.95, 0.98, 0.88, and 0.92 respectively.

24. Using the same data as the previous question, draw a reliability block diagram and calculate the overall system reliability if only 1 out of the 4 pieces of equipment was needed to manufacture the product.
25. Assuming that the reliability of each individual piece of equipment was improved to the highest level of reliability for the single piece of equipment, draw a reliability block diagram and calculate the overall system reliability if 2 of the pieces of equipment were needed to manufacture the product.
26. Describe what is meant by the term asset life cycle cost.
27. What must one focus on in order to design for reliability and maintainability
28. What is the problem with ambiguous reliability specifications?
29. What are the key elements of reliability specifications?
30. Other than the key elements of reliability specifications, what are the other requirements and specifications that should be included?
31. What analyses should be performed during the design phase?
32. Give at least 10 different examples of what should be included on a design review checklist.

$\lambda = \frac{8}{20 \times 1000} = 0.0004/\text{Hour}$

$MTBF = 2500$

$MTTF = \frac{5000}{8} =$ 624 Hours

$\lambda = \frac{1}{MTTF} = \frac{1}{625} = 0.0016/\text{Hour}$

$\lambda = 0.00202/\text{Hour}$

$MTTF = \frac{1}{0.00202} \approx 495$ Hour

≈ 20 days & 15 hours

Research Questions

(Always cite your references when answering research questions.)

1. Using resources outside this book, discuss the trend in maintenance productivity in the last 50 years.
2. Research new alternative maintenance work flow processes.
3. Research work order status codes and how they fit into maintenance work flow process.
4. Research work classifications and how they fit into the maintenance work flow process.
5. Describe an alternative work priority system. Evaluate whether it is better or worse than the one described in this book and why.
6. Research alternative backlog management methods. Which do you think is the best? Explain why you selected that method.
7. Research planning best practices other than those described by Doc Palmer.
8. Research scheduling best practices other than those described by Doc Palmer.
9. Research best practices regarding turnarounds/shutdowns.
10. Describe the process whereby wrench time information can be collected in an organization.
11. Discuss improvements to maintenance processes that would increase wrench time.
12. Identify and describe alternative measures of performance related to work management, planning, and scheduling.

$R(20) = e^{-20/300} = 0.9355$

$R(100) = e^{-100/300} = 0.7165$

$MTBF = \frac{12}{3600} = 300 hr.$

Chapter 7
Operator Driven Reliability

Reliability cannot be driven by the maintenance organization. It must be driven by the operations...and led from the top.
— Charles Bailey

Chapter 7: Operator Driven Reliability

7.1 Introduction
7.2 Key Terms and Definitions
7.3 The Role of Operations
7.4 Total Productive Maintenance (TPM)
7.5 Workplace Organization: 5S
7.6 Overall equipment Effectiveness (OEE)
7.7 Measures of Performance
7.8 Summary
7.9 Self Assessment Questions
7.10 References and Suggested Reading

Chapter 7's Objective ... to understand

- The role of operators in sustaining and improving reliability
- Total Productive Maintenance (TPM) and its implementation
- Overall Equipment Effectiveness (OEE)
- Workplace design
- Implementation of the 5(6) -S program to optimize productivity

Introduction

- The objective of the maintenance and reliability organization is:
  - To ensure that assets are available to produce quality products
  - To provide quality service in a cost-effective manner when needed
- The performance of an asset is based on three factors:
  - Reliability (inherent) — How was it designed?
  - Maintenance plan — How will it be maintained?
  - Operating environment — In what environment and with what methods will it be operated?

Operating Environment

The third factor, the operating environment, will be discussed in this chapter.

- This factor includes (1) skills of the operators and (2) operating conditions under which the asset performs.
- Several studies indicated > 40% of failures directly result from operational errors or unsuitable operating conditions.
  - Failures due to faulty inherent design can also be minimized or eliminated if operators understand the asset and how its operation affects overall performance.
  - Operators must feel responsible for proper operation of assets under their control because they sense if something is wrong or abnormal about that asset's operation.

Consider weather changes and differences

ie: blue mountains vs CBD areas.

Consider country side cold temperatures

Not an Operator-Involved Culture

- Many organizations have not successfully involved operators in maintenance because of previous work cultures that did not encourage operator involvement.
- Two primary reasons for previous work culture:
  - Division of operations and maintenance labor
  - Historical reward system
- Division of labor prevented operator-driven reliability:
  - Production/operations department operates the assets, without regard to maintenance needs or proper operating conditions.
  - Maintenance department fixes assets when they break, restoring assets to an optimum operational state.
- Reward system misaligned with operator-driven reliability:
  - Design rewarded for achieving functional capability at lowest cost.
  - Operations rewarded when meeting or beating production.
  - Maintenance teams rewarded for fixing asset failures.

What Should Be Operations' Role in Maintenance?

Operator-Involved Culture

- Operations and maintenance need to work together cohesively to deliver high-quality products waste-free and cost-effectively.
- Virtually every major management philosophy and methodology today recognizes and fosters the integral relationship between these.
- The Just-In-Time (JIT) and Lean Manufacturing methods would not be possible without high levels of asset reliability and availability, driven by active operator involvement in maintenance.

Operator-Driven Reliability

- Operator involvement is an integral part of an overall proactive maintenance strategy.
- This concept is best characterized as:
  - Operator-driven reliability (ODR)
  - Operator-based reliability (OBR)
- ODR's objective is to help plants run better, longer, cost-effectively, and competitively by:
  - Reducing unplanned downtime
  - Increasing uptime of production processes and associated assets
  - Proactively identifying problems to eliminate or reduce failures, thereby increasing reliability
- This concept is similar to TPM.

What Is TPM?

TPM

- Total Productive Maintenance (TPM) :
  - Is a team-based asset management strategy
  - Emphasizes cooperation between operations and maintenance departments
- TPM has multiple objectives and goals:
  - Achieve zero defects, zero breakdowns, and zero accidents within all functional areas of the organization.
  - Involve people at all levels of the organization.
  - Implement an effective workplace design.

minimize redundant work

Create more efficient workspace

Quicker access to tools

TPM Principles

TPM is based around the following principles:

- Improving asset and equipment effectiveness
- Autonomous maintenance by operators
- Servicing, adjustments, and minor repairs
- Planned maintenance by maintenance department
- Training to improve operations and maintenance skills
- Better workplace design, including cleanliness and the standardization of procedures

TPM Pillars

- *Pillar #1* Autonomous Maintenance
- *Pillar #2* Focused Improvement — Kaizen
- *Pillar #3* Planned Maintenance
- *Pillar #4* Quality Maintenance
- *Pillar #5* Training and Development
- *Pillar #6* Design and Early Equipment Management
- *Pillar #7* Office Improvement
- *Pillar #8* Safety, Health, and Environment

TPM Steps

1. Announce TPM.
2. Launch formal education program.
3. Create an organization support structure.
4. Establish basic TPM policies and quantifiable goals.
5. Outline detailed master deployment plan.
6. Kick off TPM.
7. Improve effectiveness of each piece of equipment.
8. Conduct training to improve operation and maintenance skills.
9. Develop an early equipment management program.
10. Continuously improve.

Company change program utilizes this steps

TPM vs. TQM

Total Productive Maintenance (TPM) closely resembles Total Quality Management (TQM):

- Total commitment to the program is needed from upper level management.
- Employees must be empowered to initiate corrective action.
- A long-term strategy is required; it may take a long time to implement programs and make them a part of the routine, ongoing process.
- Cultural change — new mindsets are required.

Benefits of TPM

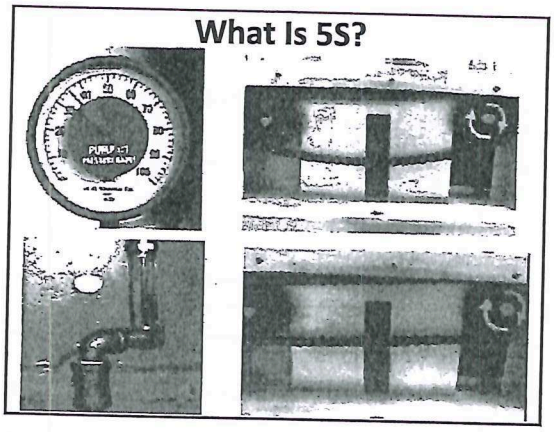
- Increased productivity
- Reduced manufacturing cost
- Reduction in customer complaints
- Satisfy the customer's needs by 100%
  - Delivering the right quantity
  - At the right time
  - With best, required quality
- Reduced safety incidents and environmental concerns

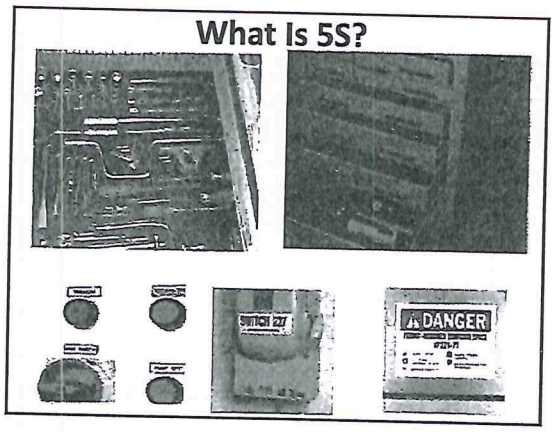
What Does 5S Mean?

What Is 5S?

- A technique to reduce waste and optimize productivity by maintaining an orderly workplace and using visual cues to achieve more consistent operational results.
- A structured program to achieve total organization-wide cleanliness and standardization in the workplace.
- 5S stands for 5 Japanese words that have been translated into their English equivalents:
  - Sort (Seiri)
  - Set-in-Order (Seiton)
  - Shine (Seiso)
  - Standardize (Seiketsu)
  - Sustain (Shitsuke)

  Many organizations have added sixth S-word to represent Safety.





OEE or TEEP?

Both or Neither?

OEE vs. TEEP

- Overall Equipment Effectiveness (OEE)
  - OEE is a key metric used in TPM and Lean Manufacturing programs to measure the effectiveness of TPM and other initiatives.
  - It provides an overall framework for measuring production efficiency.
- Total Effective Equipment Performance (TEEP)
  - TEEP is another related metric that is based on 24 hours per day and 365 days per year operations.
  - TEEP also considers equipment utilization.

OEE vs. TEEP

- Overall Equipment Effectiveness (OEE)

  OEE = Availability × Performance × Quality
- Total Effective Equipment Performance (TEEP)

  TEEP = Utilization (U) × Availability (A) × Performance (P) × Quality (Q)

  or

  TEEP = Utilization (U) × OEE

Consider how frequently the machine is used ie: It will be off over Christmas period

Calculating OEE

- A given asset, a machining center, experiences the following:

  Asset Availability = 88%

  Asset Performance = 93%

  Production Quality = 95%

  OEE = (A) × (P) × (Q)

  OEE = (88%) × (93%) × (95%)

  OEE = 77.75%

Calculating TEEP

- Using data from the previous example and operation of 20 hours/day, 300 days/yr:

OEE = 77.75%

Utilization = (20 × 300) / (24 × 365)
= 68.49%

TEEP = (OEE) × (U)
= 53.25%

Additional example shown on pages 210-213 in book.

Operator-Driven Reliability Measures of Performance

- Downtime as % Scheduled Hours
- 5S Audit Results
- Asset Performance (Throughput)
- % Ops Personnel Involved in Improvements
- % Operators Qualified/Certified
- % Assets Ready
- OEE
- TEEP

Summary

- Operator-driven reliability (ODR) and Total Productive Maintenance (TPM) strategies encourage participation of all employees, especially operators.
- Under ODR/TPM concept, equipment operators become owners of their assets, working closely with maintainers to preserve assets in best possible condition.
- Operators perform various maintenance:
  - Clean & lubricate equipment
  - Minor adjustments, checks, and fixes

Summary

- 5S (a visual workplace system)
  - Can achieve total organization-wide cleanliness and standardization of the workplace.
  - Results in a safer, more efficient, and more productive operation.
  - Boosts morale of employees, promoting a sense of pride in their work and ownership
- 5S has 5 elements:
  - Sort, Set-in-Order, Shine, Standardize, and Sustain
  - 6th element (Safety) sometimes added

Summary

- Overall Equipment Effectiveness (OEE)
  - Key metric that quantifies how well an asset or manufacturing process performs relative to its designed capacity during periods when it is scheduled to run
  - OEE = Availability × Performance × Quality
- Total Equipment Effectiveness Performance (TEEP):
  - Related to OEE
  - Includes Utilization component
  - TEEP = OEE × Utilization

Chapter 7 Self-Assessment Questions

1. Explain operator-driven reliability. Why is the operator's involvement important in maintenance?
2. Define TPM. What are TPM's various elements (the pillars of TPM)?
3. How do we implement TPM?
4. Define OEE. How do we measure it?
5. What is the difference between OEE and TEEP?
6. Explain 5S. What benefits do we derive from implementing 5S?
7. What is the difference between 5S plus or 6S (and traditional 5S)?
8. Explain what is meant by the visual workplace.
9. Explain Muda, Mura, and Muri.
10. What are the benefits of standardizing?

Chapter 7 Comprehension Assessment Questions

1. What is the objective of a maintenance and reliability organization?
2. What are the three factors that the performance of an asset based upon?
3. Approximately what percentage of failures is the direct result of operational errors or unsuitable operating conditions?
4. What is one result of operators not identifying incipient problems and correcting them in time?
5. What are the two primary reasons for a work culture that does not involve operations in maintenance activities?
6. What is the objective of OEE?
7. What is utilization rate?
8. What basic maintenance activities outside their normal operator duties may the operator perform under an operator-driven reliability concept?
9. What are the principles on which TPM is based upon?
10. Describe the origin of TPM.
11. What are the similarities between the TPM and TQM programs?
12. What are the similarities when implementing TPM and TQM?
13. What are the objectives of TPM?
14. What are the benefits of TPM?
15. How does TPM create a positive work culture and environment?
16. What are the goals of autonomous maintenance?
17. One of the goals of focused improvement activities such as Kaizen?
18. What are six major losses that can become a focus area of kaizen teams to improve effectiveness of an organization?
19. What factors are taken into consideration for maintenance prevention design?
20. What are the 5 elements of 5S?
21. Draw a diagram to illustrate the concepts of OEE and TEEP and relationship between the two calculations.
22. Calculate OEE and TEEP for a facility based on the following data: 80% availability, 99% performance, 95% quality, and 75% utilization.
23. Calculate OEE and TEEP based on the following data: 5600 hours uptime, 400 hours downtime, expected production based on design of 1000 units per production run, actual production of 850 units per production run, 50 units defective per production run, no demand for 2760 hours per year.
24. Draw a diagram of the OEE and TEEP components based on the previous data.
25. What are the benefits of TPM?

Research Questions

(Always cite your references when answering research questions.)

1. Describe at least one company's transformation to an operator-driven reliability culture.
2. Contrast the positive and negative attributes of a division of labor between operations and maintenance.
3. Research the approaches taken by maintenance management teams to convince maintainers to take a pay cut by reducing overtime when transitioning to an operator-maintainer concept.
4. Discuss the relationship between Just-in-Time/Lean Manufacturing and an operator-driven reliability culture.
5. Give a detailed history of the development of the TPM concept.
6. Compare and contrast TPM and TQM philosophies.
7. Discuss how some companies consider maintenance a non-value-added function.
8. Research how continuous improvement tools — such as Pareto, 5-Why, and FMEA — can be used to reduce operations losses and improve operational effectiveness.
9. Describe the concept of Maintenance Prevention or Design and Early Equipment Management.
10. Research activities performed by different organizations to better organize their workplace.
11. Discuss best practices in labeling and identifying operations and maintenance items as well as assets in creating a visual workplace.
12. Describe how cleaning and proper housekeeping can be an important part of achieving operations and maintenance effectiveness.
13. Research standardization practices that different organizations are using to improve their operations and maintenance programs.
14. Discuss how sustainment and discipline are carried out in an organization in order to effectively manage an operations and maintenance organization.
15. Contrast the positive and negative reasons for measuring OEE in an organization.
16. Contrast the positive and negative reasons for measuring TEEP in an organization.
17. Discuss what facilities are doing to evaluate and improve asset performance.
18. Discuss what organizations are doing to evaluate and improve quality.
19. Research new measures that could be used to evaluate and improve an organization's implementation and sustainment of an operator-driven reliability culture.

Type Test Report

Motor tested in accordance with IEC60034-2-1 & AS/NZS1359.102.3.Efficiency as per IEC60034-2-1
(PLL determined from residual loss)

SHANGHAI TOP MOTOR CO., LTD
No.303 Kangliu Road
Kang Qiao Industrial Area
Pudong, Shanghai, China

Ph: 86 15000088129
zk@techtop.net.cn
www.techtop.com

Type: TAI 200L-8
TR Number: 2013031401
Test Lab: Techtop factory

Nameplate:

Type:	TAI 200L-8		Duty:	S1	IP:	55
Serial No:	201301016021		Ins.Cl:	F	KG:	
Voltage	Hz	kW	A	cos fi	r/min	Eff.[%]
400/690	50	15	31.9/18.5	0.75	730	90.6
Brg.DE:	6312 RZ		Brg.NDE:	6212 RZ		

No Load Test:

	Voltage [V]	Current [A]	Input [W]	Freq. [Hz]	Speed [min^{-1}]	Torque [Nm]	Output [W]	Power Factor	Eff. [%]
No load	380	15.79	516	50	750	0.0	0	0.05	0.0
No load	**400**	**17.50**	**598**	**50**	**750**	**0.0**	**0**	**0.05**	**0.0**
No load	420	19.85	720	50	750	0.0	0	0.05	0.0

Load Test:

Load [p.u]	Voltage [V]	Current [A]	Input [W]	Freq. [Hz]	Speed [min^{-1}]	Torque [Nm]	Output [W]	Power Factor	Eff. [%]
0.25	400	18.26	4409	50	746	48.0	3750	0.35	85.1
0.5	400	21.67	8329	50	742	96.5	7500	0.55	90.0
0.75	400	26.32	12368	50	737	145.7	11250	0.68	91.0
1	**400**	**32.02**	**16551**	**50**	**732**	**195.6**	**15000**	**0.75**	**90.6**
1.25	400	38.57	20903	50	727	246.3	18750	0.78	89.7
1.5	400	45.77	25446	50	721	298.0	22500	0.80	88.4

Full Load At 380V & 420V

	Voltage [V]	Current [A]	Input [W]	Freq. [Hz]	Speed [min^{-1}]	Torque [Nm]	Output [W]	Power Factor	Eff. [%]
380V	380	32.48	16599	50	730	197.4	15000	0.78	90.4
420V	420	32.09	16571	50	734	196.7	15000	0.71	90.5

Locked Rotor Test:

Un (V)	Ik (A)	Pk(W)	Tk (Nm)	cosφ
400/690	231.6	76117	517.8	0.47

Temperature Rise:

Amb.Temperature:	25.5	[℃]	Winding temperature rise:	57.6	[K]
Cold Resistance:	0.383	[Ω]	Frame:	49	[℃]
Hot Resistance:	0.471	[Ω]	Bearing:	52.1	[℃]

Torque And Current:

Locked Rotor Tor./Rated Tor.: 2.63	Breakdown Torque/Rated Torque: 3.18
Locked Rotor Cur./Rated Cur.: 7.23	Pullup Torque/Rated Torque: 2.05

Check: Zhang Kai	Operator: Li Jian	Test Date: 14-Mar-13

Motor Data Sheet

TECHTOP AUSTRALIA

Output kW	15
Pole	8
Frame Size	200L
Voltage	415/690 50Hz, 440/460/480 60Hz
Motor Series	TAI
Construction	Aluminium
Type	TEFC
Protection	IP55
Insulation Class	F with Class B rise
Ambient	-20^{0}C to +40^{0}C at 1000 MASL
IEC Standard	IEC 60034 & 72
Duty	S1
Full Load RPM	730
Full Load Current @ 400V	31.9 A
Starting Current Ratio	7.23
Full Load Torque (Nm)	195.6
Starting Torque Ratio	2.63
Break Down Torque Ratio	3.18
Pull Up Torque Ratio	2.05
Efficiency @ 100% load	90.6%
Efficiency @ 75% load	91.0%
Efficiency @ 50% load	90.0%
Power factor @ 100% load	0.75
Power factor @ 75% load	0.68
Power factor @ 50% load	0.55
Noise Level dB (A) @ 1 metre	66
Output kW @ 440/460/480V	16.5/17.2/18.0
Full Load RPM @ 60Hz	876
Full Load Current @ 440/460/480V	29.0/27.7/26.6 A
Vibration Limit	2.8 mm/sec
Bearing Make	NSK
Bearing Type D.E./N.D.E	Ball/Ball
Bearing Size D.E./N.D.E.	6312ZZ/6212ZZ C3
Motor Mass	168 kg
Thermal Protection	PTC 150^{0}C

Note: This data sheet has been issued for our standard TAI series and is subject to change without prior notice.

Assessment event 3 of 3: Skills

Criteria

Unit code and name

UEECD0013 | Develop and implement energy sector maintenance programs

Qualification/Course code and name

Select your Qualification/Course code and name from the dropdown.

UEE50420 | Diploma of Electrical Engineering

Student details

Student name

Student number

Version:	20231212
Date created:	07 November 2023

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RTO Provider Number 90003 | CRICOS Provider Code: 00591E

This assessment can be found in the TAFE NSW Learning Bank.

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Assessment instructions

Table 1 Assessment instructions

Assessment details	Instructions
Assessment event overview	The aim of this assessment is to assess your knowledge and performance required to develop and implement energy sector maintenance program. This assessment is in 3 parts: • Part 1: Prepare maintenance requirements for the energy sector • Part 2: Develop and implement the maintenance program • Part 3: Evaluate the maintenance program And is supported by: • A submission checklist • Checklist • Assessment feedback **Note**: This assessment may contain links to external resources. Access to the long URL is provided via the **Error! Reference source not found.** section located at the end of this document.
Unit assessment guide	Refer to the unit assessment guide (UAG) before attempting this assessment event. The UAG contains information including assessment requirements and how to achieve a satisfactory result.
Special assessment conditions	This assessment will be conducted under the following special conditions: • This is partially supervised assessment. Students must do their own research to gather required information about maintenance requirements, regulations etc. • Time allowed to complete the assessment, 2 hours indicatively. However, students are required to spend additional time in gathering relevant information.

Assessment details	Instructions
Submission instructions	When you complete this assessment: • read the checklist at the end of the assessment to make sure you have completed everything • keep a copy of all the electronic and hardcopy assessments you submit to TAFE NSW • make sure you have completed the assessment declaration before you submit.

Task instructions

The assessor will use the criteria outlined in the following parts to determine if you have satisfactorily completed this assessment event. Follow these instructions to ensure you demonstrate the required knowledge and skills.

Scenario

You are working as the Maintenance Controller of a company named Polyteralate Manufacturers, a manufacturing company which produces a range of plastic products.

The company has purchased a new 15kW induction motor to operate one of their new Injection Moulding machines.

The motor has been installed and commissioned by a qualified technician under the guidance of the motor supplier.

It is the standard practice of the company to maintain the equipment to the highest standard and be available for service all throughout the year. Routine inspections are carried out before and after any equipment is rented out for a customer.

As the Maintenance Controller, you must inspect the installation and develop a maintenance schedule for the newly purchased 15kW induction motor. You must include **at least ten different items** in the schedule.

This is a scenario only, and you may select the owner's manual, warranty information, and any other relevant information on any suitable induction motor.

An example of –

an induction motor:

https://techtop.com.au/products/TAI-200/

Motor Data Sheet:

https://techtop.com.au/wp-content/files_mf/TAI/200/15kW%208P%20TAI%20200L%20Data%20Sheet.pdf

Part 1: Prepare maintenance requirements

In this part, you are required to complete the following tasks in preparation for developing and implementing the maintenance program of the diesel generator.

Task 1: Gather information

Research the following information to prepare to develop your maintenance program.

1. Identify WHS processes and control measures required to follow when you are preparing to develop the maintenance schedule. What are the resources required and safety measure you should follow in the company before starting the assigned task.?

- Work with TECHTOP WHS
- Ensure office is clean and that there are no trip hazards etc

2. Obtain the owner's manual, warranty information and any other relevant information about the equipment given in the scenario and capture relevant information in the following table.

   Provide the weblink to the documentation.

Table 2 Product information

Product Information	Specific product details
Weblink	www.techtop.com
Product Brand and Model No.	TECHTOP TAI-200L
Motor type	3 PHASE INDUCTION MOTOR
Serial Number	20130101602 1
~~Motor type~~	
Output Power	15 KW

Product Information	Specific product details
No Load Voltage	400 V
No Load Current	17.5 A
Phase	3
R.P.M	730 RPM.
Power Factor	0.75
No of Poles	8

3. Identify the Australian Standard for Rotating Electrical Machines Rating and Performance, specifying standard duties, ratings, operating conditions and performance.

AS 60034.1-2009
Rotating electrical machines, part 1 rating & performance
Specifies rating and performance for electrical machines

4. According to the Standard referred to in question 3, what is the maximum ambient air temperature for a rotating machine?

-20° +40° at 1000 MASL

Task 2: Develop a maintenance requirements checklist

1. Obtain maintenance requirements from the owner's manual and other relevant documents to prepare a maintenance checklist. Use the information you gathered in Task 1 on WHS and industry standards to assist you with the checklist.

   Determine maintenance requirements of different parts of the motor and the frequency of maintenance work.

   Develop the management system to record maintenance work in the **Maintenance requirements checklist** in the following table.

Maintenance requirements checklist

Table 3 Maintenance requirements checklist

Item or parts of the equipment	Frequency of service/maintenance	Relevant standard / Specification
Surroundings	Everyday	
Lubrication	Every 15,000 hrs of use or 6 month	
Air intake inspection	Every month	
Inspect for signs of dust and debris	Every month	

Item or parts of the equipment	Frequency of service/maintenance	Relevant standard / Specification

2. Identify the appropriate equipment required to perform maintenance work. KE1

Workshop manual for machine, voltage tester, Insulation tester, resistance meter, Ammeter, hand tools lifting aids, PPE

3. Identify the risks associated with the failure of individual parts in the motor. To complete the risk profile, discuss these risks with relevant persons, such as the assessor or customers, and gather information from other sources, such as internet forums.

Risk profile

Table 4 Risk profile

Failure Mode	Risk

Failure Mode	Risk

4. Identify systems required to manage and record maintenance work.

Part 2: Develop and implement the maintenance program

Complete the maintenance program schedule based on your research and analysis of maintenance tasks in Part 1.

Task 1: Develop the Periodic Maintenance Schedule and procedures

Assuming that the motor was in service for twelve months, complete the Periodic Maintenance Schedule based on the Maintenance requirements checklist (in Part 1) for the past ***twelve months*** in service. Clearly mark the correct frequency /time intervals of servicing the different parts.

Periodic Maintenance Schedule

Table 5 First twelve months maintenance schedule

Item	Maintenance Item	Machine details	Equipment or parts required	Implementation procedure	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12
1					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
2					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
3					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
4					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
5					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
6					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
7					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
8					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
9					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
10					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Item	Maintenance Item	Machine details	Equipment or parts required	Implementation procedure	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12
11					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
12					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
13					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
14					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
15					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Task 2: Apply risk control measures

To complete this task, refer to the Risk Profile you generated in Part 1 Task 2, and select 3 risks from your list. Outline the risk control measures to be taken to prevent any damages or injuries from those risks.

Table 6 Most dangerous risks

Risks	Risk control measures

Part 3: Evaluate the maintenance program

You have conducted the scheduled maintenance in the scenario for the first month.
You are required to review the Maintenance Schedule for quality assurance purposes.

Task 1: Review the Maintenance Schedule

1. Review the completed Periodic Maintenance Schedule from Part 2 with another student or your assessor/supervisor and identify *at least one improvement* to the program. Record the area or section of the schedule you have identified for improvement.

Task 2: Revise the Maintenance Schedule

Make the change identified for the improvement in Task 1 and complete the table below.

Revised Periodic maintenance schedule

Table 7 Revised Periodic Maintenance Schedule

Item	Maintenance Item	Machine details	Equipment or parts required	Implementation procedure	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12
1					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
2					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
3					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
4					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
5					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
6					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
7					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
8					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
9					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
10					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
11					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Item	Maintenance Item	Machine details	Equipment or parts required	Implementation procedure	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12
12					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
13					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
14					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
15					☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Submission checklist

Submit the following for marking:

☐ This completed Assessment Event 3 of 3 Skills

Checklist

The assessor will use this checklist while observing you completing your assessment. Read the checklist to understand what skills you need to demonstrate/ items you need to complete or submit. You must meet all the criteria.

Note that S = Satisfactory and U/S = Unsatisfactory.

Table 8 Checklist

Task number	Did the student do the following?	S	U/S	S	U/S	Assessor comments Describe the student's ability in demonstrating the required skills and knowledge. Record your observations in enough detail to demonstrate your judgement of the student's performance against the criteria required.
Part 1 Task 1	Gather information	☐	☐	☐	☐	Date: The student: ☐ Identified WHS processes and control measures ☐ Obtained the owner's manual, warranty information and any other relevant information and provided the website link ☐ Completed Product information table ☐ Identified the relevant Industry standard
Part 1 Task 2	Develop a maintenance checklist	☐	☐	☐	☐	Date: The student: ☐ Obtain maintenance requirements from the owner's manual ☐ Completed the maintenance checklist ☐ Identified the appropriate equipment required to perform maintenance work ☐ Identified the risks associated with failure and completed the table ☐ Identified systems required to manage and record maintenance work
Part 2 Task 1	Develop scheduling and procedures for the Diesel Generator	☐	☐	☐	☐	Date: The student: ☐ Identified the most dangerous risks and outline the risk control measures ☐ Completed the maintenance schedule

Task number	Did the student do the following?	S	U/S	S	U/S	Assessor comments Describe the student's ability in demonstrating the required skills and knowledge. Record your observations in enough detail to demonstrate your judgement of the student's performance against the criteria required.
Part 3 Task 1	Review the Maintenance Schedule					Date: The student: ☐ Reviewed the schedule and identified at least one improvement
Part 3 Task 2	Revise the Maintenance Schedule					Date: The student: ☐ Made the change identified for improvement ☐ Completed the revised Periodic Maintenance Schedule table

External resources – Links and URLs

Long URLs and permalinks are provided for access to content when the assessment is not used digitally, for example, not clickable.

Table 9 Long URLs

Resource Name	Long URL
The Learning Bank	https://share.tafensw.edu.au/share/home.do
TAFE NSW Assessment Guidelines	https://share.tafensw.edu.au/share/items/d36df03f-9651-4d43-8c9d-a299699e8585/0/?attachment.uuid=30e52f91-8a9f-4df1-bf7f-91168307cfb9
induction motor	https://techtop.com.au/products/TAI-200/
Motor Data Sheet	https://techtop.com.au/wp-content/files_mf/TAI/200/15kW%208P%20TAI%20200L%20Data%20Sheet.pdf

This page is not required for online assessment submissions.

Student assessment declaration

This assessment is my original work and has not been:

- copied from any source without proper referencing
- written for me by any other person except where such collaboration has been approved by a teacher or assessor.

Student signature and date

Reasonable adjustment

☐ Reasonable adjustment was in place for this assessment event.

If so, please provide details of any reasonable adjustment strategies that were implemented:

[Insert reasonable adjustment strategies]

Assessment outcome

☐ Satisfactory ☐ Unsatisfactory

Comments

[Insert comments]

Assessor name, signature and date

Student acknowledgement of assessment outcome

[Would you like to make any comments about this assessment?]

Student name, signature and date

POWER SUPPLY & CAPACITOR FAILURE ANALYSIS

Task 2: Results and discussion

For the results and conclusions section, you will analyse and compile research information for your final report.

You must structure the results and conclusions section of your report into **3 distinct sub-sections indicated by the following headings:**

- "2.1 Analysis and presentation of data sets provided"
- ~~"2.2 Collection, analysis, and presentation of data from a questionnaire"~~
- ~~"2.3 Analysis and presentation of data sourced from the internet"~~ IGNORE

Include all task numbers as outlined in the task instructions throughout the results and discussion section of your report.

2.1 Analysis and presentation of data sets provided

For the first sub-section, you will analyse different data sets using statistical methods and create graphs and charts that you must include in the '~~Results and conclusions section~~ APPENDIX of your report. Each graph/chart must be presented as a Figure in your ~~report~~, THE APPENDIX and you must provide a brief, written summary for each Figure describing the main trend/s (less than <50 words per Figure) and provide answers to any questions.

2.1.1 The data set in Table 3 represents the results of a fictional analysis of the service life of 30 instances of 3 different types of power supply in many installations.

- Produce a frequency table for the service life of each power supply. Show all in a common table and express in 5-year intervals.
- Produce a histogram for the service life of the power supplies based on the frequency table.
- Discuss the service life of the 3 power supplies. Discuss the general shape of a histogram. Provide some clarification as to why the service life histograms and frequency tables may look like this (for example, bathtub plot, preventative maintenance, installation conditions, and so on).
- Given the data provided which type of power supply would you recommend? Justify your answer.
- ~~Add the frequency table, histogram, and answers to the discussion statements and question to your report.~~

3

Table 3 Service life of power supply A, B, and C (duration in years)

Power Supply A	Power Supply B	Power Supply C
16	18	8
5	5	8
12	2	11
14	14	9
18	10	12
13	10	13
13	13	12
10	19	18
12	17	11
10	11	10
7	10	17
19	12	18
9	19	10
17	21	16
20	26	12
23	11	16
14	6	15
12	12	9
9	17	16
11	18	16

Power Supply A	Power Supply B	Power Supply C
2	11	8
8	9	12
11	22	9
7	5	18
0.5	27	11
10	23	8
15	6	9

2.1.2 Nature of capacitor failures

Capacitor failures are a known failure mode of common power supplies. For this task, the aim of this task is to try to understand the nature of failing capacitors. We will progress in a series of steps to approach a greater understanding of the nature of this issue.

VERY IMPORTANT →

Let us say that we work as part of a supply chain for electronic components. Several clients have provided anecdotal evidence of failing capacitors. We want to see if there is indeed a problem, we want to ascertain if there are any patterns, and we want to gauge the extent of the problem.

You are provided with some fake data on capacitors. Reference this data as "UEECD0010 supplied data".

2.1.2.1 Firstly, you will be provided with data from a 'survey' from 3 different suppliers. We asked them for the number of capacitors sold over the last 5 years. Each supplier sells a unique range of capacitors.

This may indicate to us the potential scale of any issues.

Use the data in Table 4 to create a pie chart in colour and a bar chart in black and white. Add these as figures to your report and add a brief, written description.

4

Table 3 Capacitors sold from three suppliers X, Y and Z (last 5 years) THIS IS SAMPLE → NOT POPULATION

Supplier	X	Y	Z
Number of capacitators sold	8200	6400	18000

2.1.2.2 Furthermore, we also obtained an approximation of the number of failures of these capacitors.

An aircraft manufacturer was supplied with several units from X, Y, and Z suppliers. Each supplier sold a different type of capacitor to the aircraft manufacturer. Detailed records have been kept and the number of failures accurately recorded. All units were supplied – and the assumption is made that they were put into use – at the same time.

Capacitors are a non-repairable part. But we can approximate this and use the Mean Time Between Failures (MTBF) formula. Use the data in Table 5 and the formula provided to calculate MTBF. Complete Table 6 and add it to your report.

5

Table 6 The number of failures of capacitors from X, Y, and Z suppliers after approximately 44,000 hours of service

Supplier	X	Y	Z
Number of capacitors sold	8200	6400	18000
Number of capacitor failures	30	32	164

Calculate the Mean Time Between Failures (MTBF):

- θ = MTBF
- $\theta = T / R$
- T = Time (number of # units * hours service)
- R = Number of failures
- MTBF = $1 / \lambda$
- Or 1 / (# failures / Time).

6

Table 4 MTBF in capacitors of different suppliers

Supplier	X	Y	Z
Number sold	8200	6400	18000
Number of failures	30	32	164
T =	8200*44,000 = 360,800,000	6400*44,000 = 281,600,000	
R =	30	32	164
MTBF = θ = T / R	12,026,667		

2.1.2.3 In your report, state why the Mean Time Between Failures (MTBF) statistic may be used and why caution is required in its interpretation.

Why dont we use mean time between repair?

2.1.3 Test of degrading capacitors over time

Using the data from Table 7, we selected three groups of capacitors with the greatest number sold. We then obtained data for each capacitor on hours of use and a measure of the amount of performance degrade. Capacitors were tested at the time of sale and retested under the same conditions.

Table 7 Record of capacitors sold in class intervals of 1 microfarad

Capacitance Rating (microFarad)	Number of Capacitors
0 - <1	90
1 - <2	50
2 - <3	70
3 - <4	120
5 - <6	50
7 - <8	20

We determined capacitor degrade as a measure at the percentage output voltage divided by the input voltage. Where 100% voltage comes out from what went in, this would indicate no degrade of performance. If there was a 0% voltage output, then this would indicate a complete degrade of performance.

100% Voltage Out/Voltage In = zero degrade, 0% Voltage Out/Voltage In = 100% degrade.

2.1.3.1 Now create a scatterplot for the 3 classes of capacitors using the SAMPLE data in Table 6 Show linear trend lines. You can show a chart for each if you like but must provide a chart with all 3 groups combined. The data is a sample of 10% of each capacitance class group. For example, if the total is 120 then the sample for that group is 12 capacitors.

APPENDIX

2.1.3.2 Add the scatterplot to your ~~report~~ and provide a brief, written summary for each figure describing the main trend/s.

Hours of use = approximate time in hours

% Degrade = Voltage Out / Voltage In

8

Table 8 Hours of use by %Voltage Out/Voltage In for sample data of capacitors in class intervals of 1 microfarad

0-1 microfarad (n=9) Hours of use	Degrade (% VOut / Vin)	2-3 microfarad (n=7) Hours of use	Degrade (% VOut / Vin)	3-4 microfarad (n=12) Hours of use	Degrade (% VOut / Vin)
59	80	182	86	55	95
82	78	183	75	56	97
86	77	185	84	85	98
95	67	190	67	89	98
100	58	208	81	128	98
105	42	235	45	209	90
105	88	244	43	228	67
109	38			67	91
114	42			82	73
				111	78
				139	72
				170	73

2.1.4 Capacitor failure

We want to continue our investigation into capacitor failure.

To get more of an indication into this we obtained some data on how long a capacitor was used until it failed (Appendix 1). Capacitors can last for a very long time before they fail (some 1,000,000's of hours) and so naturalistic experiments cannot readily be performed. Instead, it is common practice to subject capacitors to more extreme and controlled conditions. This is known as Accelerated Testing.

Capacitors typically fail by open or short circuits. This may be due to electrical overstress, mechanical overstress, environmental overstress, dielectric overstress, dielectric degradation, manufacturing defects, temperature extremes, or chemical cleaning.

In the data table for capacitor hours in Appendix 1, there are 3 capacitors in the 0-1 microfarad range that did not degrade when tested – their % voltage out to voltage in the ratio was 100%. There were none in the 2-3 microfarad group that tested 100% and 1 in the 3-4 group.

Please note: In this description of % voltage out divided by voltage in, the voltage in refers to the voltage applied at the start of the test and voltage out refers to the test voltage at the end of the test, or final voltage.

So, we now equate <100% voltage out as 'Failed'. To better understand the data, we can look at the spread of time taken for each capacitor in each group to 'fail'. Think of the chart type and statistical procedure that can help us visualise spread and central tendency.

2.1.4.1 Use the data in Appendix 1 to create a data table to allow you to draw three boxplots for the 0-1, 2-3 and 3-4 microfarad groups of capacitors. Use all data excluding only those data with 100% voltage out. Produce boxplots of data for the 0-1, 2-3 and 3-4 microfarad groups of capacitors excluding only those data with 100% voltage out. Add the data table you created and the 3 boxplots to your report.

2.1.4.2 Produce boxplots of data for the 0-1, 2-3 and 3-4 microfarad groups of capacitors excluding only those data with 100% voltage out AND high and low outliers excluded. Add the boxplots to your report.

APPENDIX

2.1.4.3 In your ~~report~~, describe the distribution for the data set with outliers INCLUDED, for the:

a) microfarad group (n=87)

b) 2-3 microfarad group (n=70)

c) 3-4 microfarad group (n=119).

2.1.4.4 List the High and Low outliers for the 0-1, 2-3 and 3-4 microfarad groups of capacitors data set.

2.1.4.5 Complete tables of statistics of central tendency and dispersion for the data with outliers included (Table 9) and excluded (Table 10). Add these to your report. Use these to compare the data and address the following:

a) Discuss each capacitor group in terms of capacitor reliability.
b) What effect does excluding outliers have on the general shape of the boxplots?
c) Discuss this data in terms of Central tendency [mean, median, mode, distribution skew] and Dispersion [range, standard deviation].

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Table 7 Statistics of central tendency and dispersion, All Data - with 100% excluded, outliers INCLUDED. Standard deviations calculated using excel formula for populations: STDEVP.

	0-1 microfarad N=87	2-3 microfarad N=70	3-4 microfarad N=119
Mean		198.4	
Median			170
Mode	101	190	
Range			200
IQR			
Standard Deviation (STDEVP)	15.6		

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Table 8 Statistics of central tendency and dispersion, All Data - with 100% excluded, outliers EXCLUDED

	0-1 microfarad N=76	2-3 microfarad N=61	3-4 microfarad N=119
Mean	99.5		
Median			
Mode			
Range	36		
IQR		41	105
Standard Deviation (STDEVP)			61.8

2.1.5 Equation of regression lines

2.1.5.1 Complete Table 11 and add it to your report. Input the equation of regression, and R-squared for each capacitor class group, for both sample and all data. (You can do this in excel Format Trendline.) Then fill in the correct R correlation value and slope. Note that we will assume a LINEAR RELATIONSHIP exists between voltage degrade and hours of use for the purposes of this assignment.

Table 11 Equation of regression, R-squared correlation, R, and slope for Sample and All data of capacitor groups

y = b + mx	Sample Data			All Data		
	0-1 microfarad	2-3 microfarad	3-4 microfarad	0-1 microfarad	2-3 microfarad	3-4 microfarad
Equation of Regression Line	y = 131.4 + (-0.7161)x					
Correlation r^2		0.7857	0.3033			
Correlation Coefficient r			-0.5507			-0.7397
Slope m		-0.6143			-0.2315	-0.2345

2.1.5.2 Comment on the data in your report. Refer to Table 11 and the boxplot charts from Task 2.1.4. Refer to Appendix 2 for additional information on r-squared, r and slope.

2.1.5.3 Use the equation of regression to complete Table 12 of predicted % Voltage Out/Voltage in (Degrade). Add the completed table to your report.

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Table 4: Predicted VOut/Vin (Degrade) given for 10, 100, 150 and 300 Expected Hours of Use for Sample and All data of capacitor groups

	Sample Data	All Data
Predicted % VOut/Vin (Degrade) given at right for Expected Hours of Use:	0-1 microfarad	0-1 microfarad
10	124.24	
100		
150		-16.45
300	-83.43	
	2-3 microfarad	2-3 microfarad
10	187.80	
100		85.10
150		
300	9.65	
	3-4 microfarad	3-4 microfarad
10		
100		
150		
300	64.90	34.60

2.1.5.4 In your report, refer to Table 12 and indicate which values are valid predictions and which are unsupported extrapolations. Predications made for values from outside of the range of values used to create the regression equation are not valid and called extrapolations. Compare the predicted values given between capacitor groups and discuss the use of sample data as opposed to all the available data (all data set).

Appendix 1 – Data on capacitor failure

100% = zero failure data are marked in red. [You will not need the ***Degrade (% voltage out)*** columns. Use only the ##microfarad hours of use columns. Remove the values that have 100% Degrade (% voltage out).]

Table 1 Data table for capacitor hours of use before testing degradation measured as %Voltage Out / Voltage In.

0-1 microfarad Hours of use	Degrade (% voltage out)	**2-3 microfarad Hours of use**	Degrade (% voltage out)	**3-4 microfarad Hours of use**	Degrade (% voltage out)
50	100	91	78	40	70
52	96	94	88	43	87
55	93	95	75	47	94
56	96	95	80	47	80
57	99	102	80	49	80
58	93	105	76	49	99
59	92	110	79	53	89
59	80	116	81	55	95
59	97	139	75	56	97
63	96	145	81	61	86
73	89	145	76	62	83
80	94	146	77	63	71
82	78	148	81	64	82
83	90	148	75	67	91
83	94	159	79	67	97
84	91	182	85	73	91

0-1 microfarad Hours of use	Degrade (% voltage out)	**2-3 microfarad Hours of use**	Degrade (% voltage out)	**3-4 microfarad Hours of use**	Degrade (% voltage out)
86	77	182	86	75	71
87	98	183	75	78	73
89	85	185	84	79	90
90	97	188	87	82	73
91	93	190	78	85	98
91	88	190	67	89	98
92	99	190	75	91	84
92	88	191	68	92	71
92	100	192	79	98	94
93	89	197	66	103	88
93	97	197	75	106	100
93	100	198	70	106	95
93	92	200	58	111	78
94	93	201	66	111	78
94	88	204	63	112	82
94	93	205	68	112	95
95	91	207	82	114	87
95	67	208	81	116	98
96	27	209	52	121	71
96	19	210	58	124	91

0-1 microfarad Hours of use	Degrade (% voltage out)	**2-3 microfarad Hours of use**	Degrade (% voltage out)	**3-4 microfarad Hours of use**	Degrade (% voltage out)
96	13	211	56	127	93
97	49	212	55	127	82
97	25	215	73	128	98
98	6	216	59	131	75
98	31	216	80	131	53
98	42	216	50	131	62
98	30	218	57	132	53
99	46	219	49	132	63
99	38	221	45	133	72
100	53	221	40	138	59
100	58	224	45	138	77
100	40	225	50	139	79
101	53	226	40	139	72
101	44	226	42	140	69
101	5	227	46	141	82
101	23	227	46	143	50
101	54	228	41	144	58
101	40	232	45	148	83
102	38	235	40	151	64
102	39	235	45	151	78

0-1 microfarad Hours of use	Degrade (% voltage out)	**2-3 microfarad Hours of use**	Degrade (% voltage out)	**3-4 microfarad Hours of use**	Degrade (% voltage out)
102	22	238	41	154	56
102	8	239	41	154	67
103	12	240	41	156	75
103	24	240	46	166	70
103	40	241	41	170	78
103	39	241	42	170	73
103	49	241	47	171	83
103	9	243	45	173	51
104	32	244	43	174	76
104	16	244	48	175	70
104	19	245	42	184	58
104	16	246	50	184	82
104	29	248	48	185	82
105	22	340	76	188	76
105	42			190	65
105	88			195	67
105	35			197	84
105	23			204	79
106	39			206	72
106	32			209	90

0-1 microfarad Hours of use	Degrade (% voltage out)	**2-3 microfarad Hours of use**	Degrade (% voltage out)	**3-4 microfarad Hours of use**	Degrade (% voltage out)
107	38			210	27
107	10			211	69
107	15			212	31
107	31			213	60
109	20			215	49
109	6			216	62
109	10			216	53
109	38			216	57
109	36			217	28
110	22			217	57
110	15			217	55
114	42			218	35
116	30			219	48
139	99			221	47
				222	31
				227	54
				228	67
				230	41
				231	66
				232	30

0-1 microfarad Hours of use	Degrade (% voltage out)	**2-3 microfarad Hours of use**	Degrade (% voltage out)	**3-4 microfarad Hours of use**	Degrade (% voltage out)
				237	51
				238	40
				239	35
				240	47
				215	51
				216	62
				216	55
				216	75
				217	28
				217	57
				217	55
				218	35
				219	48
				221	47
				222	31
				227	54
				228	66
				230	41
				231	66
				232	30

0-1 microfarad Hours of use	Degrade (% voltage out)	**2-3 microfarad Hours of use**	Degrade (% voltage out)	**3-4 microfarad Hours of use**	Degrade (% voltage out)
				237	51
				238	40
				239	35
				240	47

Appendix 2 – Information on r-squared, r and slope

r-squared: r-Squared or r^2 is known as the correlation of determination. It is the proportion or fraction of the total variance (s^2) of Y that can be explained by the linear regression of Y on x. It must be remembered that this should be used only as an indicator of the fit of the line to the data, and not as a predictor for response values in the future. The greater the r^2 value the greater the degree to which the y value is determined by the x value - the greater the degree to which the % VOut/Vin (Degrade) can be explained by the number of hours in use.

r: r is the correlation coefficient. This is sometimes confused with the R-squared correlation statistic. Pearson's product moment correlation coefficient (r) is given as a measure of strength of the linear association between two variables. The value of r reflects the degree to which x and y change together: are correlated. A value of 0 means there is no correlation. A value of 1 means that there is a perfect linear correlation: +1 means that both x and y go up together, -1 means that as x goes up y goes down, and vice versa.

Slope: the slope or gradient of the line reflects the rate of change of the x and y variables. While the +ve or –ve sign of r indicates either correlation or anti-correlation between the variables, the slope reflects the change in values on the Y-axis divided by the change in values on the x-axis. In this case, the slope is the change in % voltage out divided by voltage in per change in time of use in hours – or how much a capacitor degrades per hour of use. The steeper the slope, the greater the rate of change. In this case, the slope will always be downhill and thus have a negative value.

UEECD0013 Maintenance Project

[Document subtitle]

Your Name
[Email address]
Date

Contents

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1 Form a RCM Team 2

2. Identify Stress factors for your asset (in its operating environment) 2

3. Describe the nine step RCM process ..... **Error! Bookmark not defined.**

Make headings for each step and develop a maintenance strategy for your selected block..... **Error! Bookmark not defined.**

2. Inclusion of TPM Analysis 4

2.1 Operator Driven Reliability (ODR) 4

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Overall Equipment Effectiveness Calculation (OEE) 7

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1. Introduction

Briefly state what is in this report and describe the aim of a maintenance strategy.

2. Systems Description

Write a description of your system and show a functional block diagram of your system.

3. Developing a Maintenance Strategy

1 Form a RCM Team

Make up a table (use position names) which has position, job function, and identify how that person can contribute toward the team.

2. Identify Stress factors for your asset (in its operating environment)

Note you already have identified criticalities, now the next step is to identify how the equipment is stressed.

The 9 Step Process (reduced to eight):

1. System selection and information collection.

   In this step you select the function subsystem you want to analyse. For example, Hydraulics.

   Then decide where you can collect data from to analyse this block. Sources will include service manuals, data from the CMMS, collect data from the people operating the equipment, from the maintenance staff who worked on the equipment. Discuss the quality of the data you will select and the confidence level you will have in the accuracy of the data.

2. System Boundary Definition

   In this section you define what the boundaries are of the subsystem you select to analyse, e.g., control system, or drive system. Note you already have completed a whole functional diagram. Now you are starting to focus on a subsection that you can complete within class.

3. System Description and Functional Block

   You already have the complete functional diagram, now cut and past the subsection here, but this time describe the functional interdependencies. How does one block depend on the other?

4. System functions and Functional Failures

   Describe what would happen if one block fails and what effect it has on the whole system, and how other element depend on that block within the subsystem.

5. FMEA

   This helps identify all possible failure modes. The template is in Appendix A. Use this template to document a FMEA for your most critical subsystem.

6. Selection of Maintenance Tasks

   For each identified block develop maintenance tasks. These should fall in the categories of
   PM CBM, PdM, RTF
   The look at the frequency of the tasks. Weekly, monthly 6 monthly, yearly etc

7. Task Packaging

   Package the tasks in all weekly tasks, monthly tasks, etc
   Add these tasks in your Appendix.

8. Make the Program a living one – Continuous Improvement.

   Discuss how you would monitor the new strategy and what data you would collect to monitor the effectiveness of the new strategy. How can you refine the maintenance strategy? Include an OEE calculation as a Reference that will be a base line to start from. You can then update this base line annually.

4. Inclusion of TPM Analysis

Write a paragraph of the basic concepts of TPM, and how these differ from RCM.

2.1 Operator Driven Reliability (ODR)

Discuss how ODR can improve your maintenance strategy, include your RCM based achievements in your discussion. Can ODR benefit your RCM based strategy? Justify your answer.

2.2 Improvement of Asset Effectiveness

Discuss how improvements in asset effectiveness can prove your maintenance strategy. Base this discussion on TPM principals as per page 131 of your TPM handout. This discussion should cover:

- Autonomous maintenance by operators
- planned maintenance by the maintenance team.
- Training required.
- Workplace design

4.3 Benefits of TPM

Discuss the benefits a TPM program can bring. Base this discussion on page 133 of your TPM handout. Include a discussion on 5S and OEE. Perform OEE calculations in Appendix B and refer to these calculations in your discussion.

5. Maintenance KPIs

In this section propose some KPIs that you would use to monitor your maintenance program. The KPIs should include some reliability metrics such as Failure Rate (λ) and the Mean Time Between Failures (MTBF) and how to improve MTBF.

Other metrics should include performance indicators such percentage PM tasks completed, Backlog Register work, criticalities of backlog, Failure Rates, overtime hours as percentage of total labour hours. Contractor performance etc.

6. Conclusion

Summarise the contents of your report here.

Appendix B

Overall Equipment Effectiveness Calculation (OEE)

OEE = Availability x Performance x Quality

1. **Availability**

Write a paragraph on how you will calculate the availability and where the data for this will come from. You may say the data will come form the CMMS. As you don't have real data make up some data for your project and show how you calculated the availability.

2. **Performance**

Write a paragraph on how you will calculate the Performance. State any assumptions made. State the source of your data, this data may come from Production or Quality Departments. As you don't have real data make up some data for your project and show how you calculated the performance.

3. **Quality**

Again, write a paragraph on how you may be able to measure the quality of your subsystem. State the possible source of your data and show how you would calculate Quality. Make up some data for this exercise.

4. **OEE Calculation**

Show the details of your OEE calculation and discuss the results. Explain how you will use this data to trend the success of your maintenance strategy. Your initial results will most likely not be where you would want them to be. Thus, you may set goals that should be achievable.

Appendix A

FMEA Form

Function	Failure Mode	Effects of Failure	Severity	Causes of Failure	Occurrence	Predictive Method	Detection	R.P.N.	Recommended Action	Person to Action/ completion Date	Action Completed

Bibliography

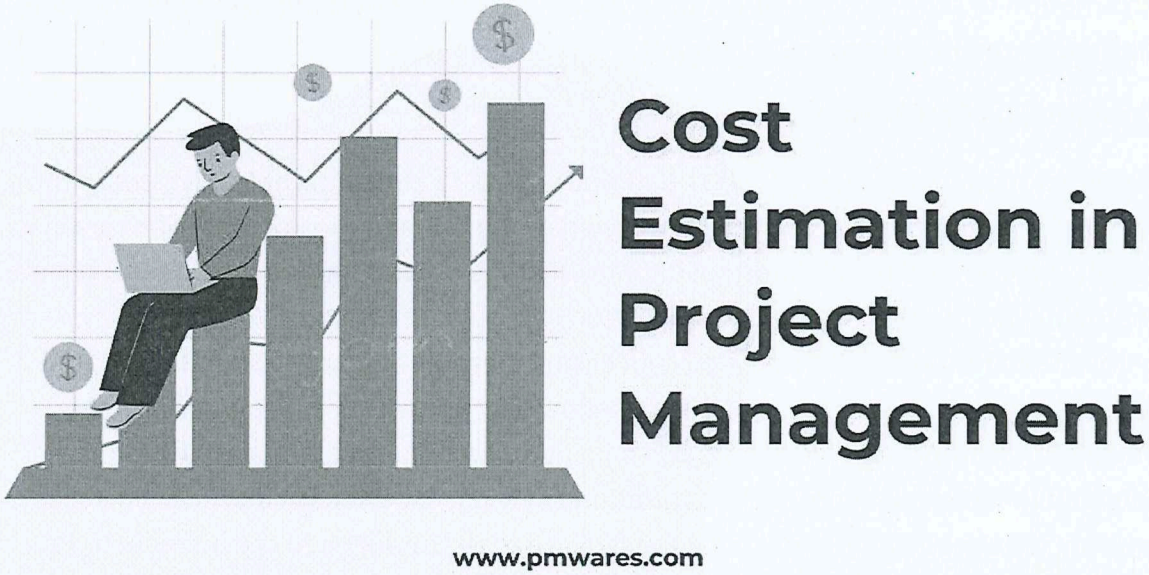
List all your references here.

Top 6 Cost Estimation Methods in Project Management

Sakshi Pande

April 24, 2024

Top 6 Cost Estimation Methods in Project Management – pmwares



What do you think is the most challenging part of a project? In a project lifecycle, While many consider managing the team as something very challenging, some might say that the effectiveness of a project is more difficult. But do you know that there is one stage that affects the entire project. It can either make a project execution easier or turn it complex if not done properly. This stage is the project planning stage. In this stage we have to set some boundaries for smooth execution of a project. As we know with increasing competition and tight budgets, projects are always expected to deliver more while spending less. This is only possible with effective project planning. In this article I will share a few methods for cost estimation of a project.

What is Cost Estimation in Project Management?

In project management cost estimation is the very important process in which we predict the financial resources required to execute a project. It involves carefully analyzing various cost factors like labor, materials, equipment, and other overhead expenses. This analysis can help you and other stakeholders to make informed decisions about project budget allocation and resource management. If you are starting out with the project cost estimation make sure to consider both direct and indirect costs. Direct costs are tangible expenses directly linked to the project, like materials and salaries. Indirect costs include other operational expenses like utilities and office

supplies. By using all these elements, cost estimation can empower project managers to set realistic budgets.

6 Project Management Cost Estimation Methods

Every project is different in terms of complexity and size. Similarly every organization follows different practices when it comes to project budget estimation. While some projects can start working based on approximate figures, some require accurate cost information to proceed. Keeping this in mind, here I have outlined 6 cost estimation methods used in project management.

1. Analogous Estimation

In project management, analogous estimation is also called comparative estimation. It offers a practical way to cost forecasting when the project information is not given in detail. This method uses historical data from some similar past projects (also called analogous projects) to estimate the cost of your current project. This is done by finding a close resemblance in terms of project scope, complexity, and deliverables. As a project manager you can establish a baseline cost for your new project using this. However, it is important to be careful while adjusting for any significant differences between the projects. Factors like variations in team experience, material costs, or external influences might make it necessary to make changes to the initial estimate derived from the analogous project.

2. Parametric Estimation

Parametric cost estimation offers a data-driven approach to project budgeting. It not only uses historical information but also statistical analysis to identify the relationships between specific project characteristics which are called parameters and the cost associated with these parameters. For example, in construction projects the square footage of a building might be a parameter used to estimate material and labor costs, so the cost per square footage from a past project can help estimate cost in the current project. This method is highly preferred in situations where good historical data exists for similar projects. By analyzing past trends, project managers can create formulas or algorithms to predict costs for the current project based on its specific parameters. This approach promotes accuracy and efficiency, especially during the early planning stages. However, the success of parametric estimation depends on the quality of historical data. Inaccuracies in past projects or a lack of projects with comparable parameters can lead to misleading estimates.

3. Experts Judgment

Expert judgment is a fundamental method in project cost estimation which is specifically used for new or unique projects. As the name suggests, It uses the experience and knowledge of subject matter experts to create a cost baseline. This

person can be a project manager, a team member with deep industry knowledge or even an external consultant.

However, expert judgment is not completely free from limitations. Since it relies on individual experience, accuracy depends on the expert's qualifications and can have some potential biases. Although there is a way to eliminate this by using experiences of multiple experts with diverse backgrounds.

4. Bottom-Up Estimation

Bottom-up estimating is a useful approach in project management that uses highly accurate cost forecasts. It handles the project by breaking it into small components, like work packages within a Work Breakdown Structure (WBS). Each work package is then examined to determine its individual cost. For doing this, you will have to consider labor hours, material requirements and any other expenses in completing that specific task. In this way the cost of each task is calculated and finally you have to accumulate these costs to estimate the final cost of the entire project. The purpose of doing this is to minimize the risk of overlooking important cost factors. However, the time and effort required for this detailed analysis can be a disadvantage.

5. Top-Down Estimation

Top-down cost estimation offers a quick way to get an approximate figure for your project's overall budget. It starts at a high level by considering factors like project scope, historical data from similar projects or expert judgment. You can also use industry benchmarks or cost per unit (cost per square foot for construction) to arrive at a preliminary budget. This initial estimate is later divided and allocated between various departments involved in the project.

Although it is fast and convenient it is not very accurate especially for complex projects. That is why generally as the project progresses and details become clearer a bottom-up estimation approach is used to define more accurate cost estimates for each work package which leads to a more precise overall project budget.

6. Three Point Estimation

Three-point estimation is a widely used tool in project management that tackles cost uncertainties by considering a range of possibilities. Unlike a single point estimate, it uses three values i.e, optimistic, most likely, and pessimistic. The optimistic estimate shows the ideal scenario with everything going smoothly. The pessimistic estimate considers potential problems and delays you can understand as representation of the worst-case cost. The most likely estimate sits between the two which shows the anticipated cost with normal circumstances.

By incorporating these three values, three-point estimation can help you to develop a more realistic cost range. The best part about this method is that it provides a range of

costs. This range also helps with emergency planning and allows project managers to set aside funds for unforeseen issues without affecting the project budget.

Conclusion

To conclude, we saw different methods of cost estimation in project management and each of these methods have different suitability and accuracy levels. For planning an accurate budget for your next project you have to use your expertise as a project manager to understand which method is most suitable for that particular project. Cost estimation is undoubtedly one of the most important parts of project planning which requires skills and some level of practice. Completing a PMP Training Program can help you develop these skills in a much easier way. So avoid stagnation in your career and take charge to become a better project manager!

Let us know in the comment section below which of the above methods do you use in your organization for project cost estimation.